Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 212 AUGUST, 1931 No. 2

THE ORIGIN OF THE SOLAR SYSTEM.*

BY

SIR JAMES HOPWOOD JEANS, KT., F.R.S., LL.D., D.Sc.

The observational astronomer generally feels only an indirect interest in the problem of how our earth and its companion planets came into being; his telescope can give him no direct information on the subject, since such planets as other suns may possess are too small and too distant to be observed. If every star in the sky were suddenly to give birth to planets we should in all probability remain unaware that anything was happening.

Yet the problem is of thrilling interest to science in its widest sense. The old nebular hypothesis of Laplace had pictured the stars as shrinking nebulæ, which rotated faster and faster as they shrank, and threw rings of matter off their equators in the process, each of which was destined in time to condense into a planet. This cosmogony implied that the shedding of planets was a normal event in the life of a star. It led to the concept, so commonly held in the nineteenth century, that every star in the sky was a sun distributing light and heat to a retinue of worlds circling round it. As solar light and heat are the most obvious essentials for terrestrial life, it was natural to take the next step and assume that every star we saw in our telescopes was busily at work radiating energy to maintain life on its surrounding planets.

* Presented at the Medal Meeting held Wednesday, May 20, 1931.

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And when once this step had been taken, no great violence to the probabilities seemed to be implied in taking the further step of assuming that each star had been created to this special end.

The more modern view which I shall put before you to-day supposes that the birth of planets is very far from being a normal event in the life of a star—it is an abnormal and exceedingly rare event. So rare is it, that even if the stars have already lived the longest lives that have ever been suggested for them—lives stretching many millions of millions of years back into the past—only a minute fraction of them can be surrounded by planets. And if they are destined to live into the future for the longest period that has ever been suggested—a period measured in hundreds of millions of millions of years—even by the end of this inconceivable length of time, only a minute fraction of stars will be surrounded by planets. This view implies that most stars must live and die without giving birth to planets at all—and, even of those that do, the majority must be so cold and shrunken before their planets are born that there can be little or no question of their sustaining life.

In brief, the older theory, with the help of a little kindly imagination, depicted a universe teeming with life. The more modern theory depicts a universe which proceeds steadfastly on its way, with life hardly coming with the picture at all. Only here and there, in insignificant corners and at infrequent intervals, a strange accident results in life stumbling into being. It can hardly be a matter of indifference to science—and still less to humanity—which picture is correct.

Let me summarise the evidence which seems to me, and I think to most astronomers, to indicate that the latter is the only tenable view.

The first piece of evidence is of a purely physical nature. The action of radium, such as we see on the hands of a luminous watch, appears at first glance to be permanent, and so it is for all practical purposes; the radium which illuminates the hands of a watch will certainly outlive the clockwork which drives them. Yet careful scientific measurement shows that it is no more permanent than anything else in nature. All radium gradually loses its potency; it deterior-

ates, so that after about 1,600 years it will be only half as potent as it is to-day.

The reason for this loss of potency is now well understood. It is that the radium gradually changes into something which is not radium, and has not the properties of radium—the débris of radium, let us call it. After 1,600 years, a mass of pure radium becomes changed into half radium and half débris of radium. The potency of the mass is reduced to half because the amount of radium is reduced to half.

It follows that if we are given a mixture of radium and its débris, we can tell how long the radium has been at work to produce this débris. For instance if the amount of débris is equal to the amount of radium, we know that the disintegration of the radium has been in progress for 1,600 years; if three quarters of the mass is débris the process has been in action for 3,200 years, and so on.

Substances which behave like radium are described as "radio-active." The time needed for a mass of a radio-active substance to change into half substance and half débris is known as the "half-value-period" of the substance; it varies enormously for different substances. It is 1,600 years for ordinary radium; for one radio-active substance, Radium C′, it is only about a millionth of a second, while at the other end of the scale are substances for which the half-value-period is measured in millions of years. For thorium it is about 22,000 million years; for uranium 4,500 million years.

Now in various rocks in the earth's crest, the geologists come upon imprisoned uranium accompanied by débris of uranium. In no case is the mass of débris ever as great as the surviving mass of the uranium. There is only one possible inference—the uranium has not been imprisoned for as long as 4,500 million years. The proportion of débris found in all samples of rock tells much the same story—the uranium has been imprisoned for a time of the order of 1,500 million years. The rocks in which thorium is imprisoned have much the same thing to say—the thorium has been imprisoned for a time of the order of 1,500 million years. We conclude that something like 1,500 million years must have elapsed since the crust of the earth solidified. To this we must add some-

thing for the time before solidification and we shall obtain the total age of the earth. From a study of the relative abundance of ordinary uranium and its isotope actino-uranium, Rutherford has been able to show that this total age cannot have been more than about 3,400 million years.

The bodies we describe as shooting-stars confirm the story told by the earth's rocks. These objects are of course not true stars at all; most of them are tiny affairs, no bigger than a pea or even a grain of sand. They earn the name of stars by behaving in a dramatic way for a few seconds close at hand, but they pay for it with their lives. Dashing into our atmosphere from outer space, they are vaporised by the air-resistance they encounter, and meet their doom of being turned into a trail of luminous gas while still many miles above the surface of the earth. Occasionally one is too large to be completely vaporised by the resistance of the air, and what is left of it strikes the earth in the form of a large rock or stone known as a "meteorite." Many of these bodies are found to contain imprisoned thorium or uranium, together with the débris of their disintegration. The amount of the latter makes it possible to estimate the length of time since the stone solidified. The time cannot be estimated with great accuracy, but no body that has been examined has suggested a period of more than 2,900 million years since solidification, and the majority appeared to be of about the same age as the earth. In a general way we may say that the length of time which has elapsed since the planets and other members of the Solar System solidified can hardly have been more than about 3,000 million years.

This estimate depends solely on recent advances in physical science. The earlier cosmogonists had no means of forming such an estimate, and it would have been of little use to them if they had. It is important for us of to-day, because we can combine it with recent astronomical knowledge. We can tell how much the sun and stars have changed in 3,000 million years. The sun is radiating its substance away at the rate of 360,000 million tons a day. This sounds like a very rapid loss of weight until we compare it with the huge total weight of the sun. We then find that radiation at this rate for 3,000 million years can hardly affect the sun's weight at all.

The weight of the sun, and indeed of all the stars, must have been very much the same 3,000 million years ago as to-day. Furthermore, we know from recent astronomical research, that the physical state of a star depends mainly, and indeed almost entirely on its weight. All stars which have approximately the same weight as the sun are found to have also approximately the same physical constitution as the sun. Thus we must suppose that when the planets and meteors were born, the sun not only had the same weight, but also the same physical constitution and size, as it has to-day.

This conclusion, based on evidence which can hardly be challenged, provides a test which we may apply to the various theories of the origin of the Solar System in turn. Let us first apply it to the most famous of all, the nebular hypothesis of Laplace. Laplace supposed that the sun started as a huge nebula, extending out as far as the orbit of the furthest known planet—to-day we must say as far as the orbit of Pluto; as it shrank with cooling, it left behind it rings of matter, which subsequently condensed and formed the separate planets. When the earth was shed, this nebulous sun would have a diameter approximately equal to the present diameter of the earth's orbit. We see at once that this hypothesis cannot survive the test just described. And indeed there are many other tests, mainly of a dynamical kind, which it is equally unable to survive.

It would be an impossible task to test in turn all the various theories of the earth's origin which might be propounded, one by one. Let us notice that they fall into two distinct classes, according as they suppose that the sun alone was concerned in the process of creating the planets, or that other bodies were concerned in addition to the sun.

Laplace's hypothesis is of course the outstanding example of the first class. The objection common to all hypotheses of this class is, that, if the sun alone were concerned, it is difficult to discover by what mechanism the outermost planets could be projected to their present distances from the sun. We seem compelled to postulate some system of internal explosions as the origin of the planets, and this appears inconsistent with the present orderly arrangement of the planetary orbits. It also fails to explain why the systems of Jupiter

and Saturn are so exactly like the main system of the sun, in every respect except size. Indeed this last similarity is so marked, that any theory which fails to explain it may safely be dismissed; the same mechanism must have produced these smaller systems as had already produced the main system. This test seems fatal to any hypothesis of explosions. It is straining probabilities far too much to imagine that a succession of explosions could produce so orderly a system as the main system of planets; it is straining them infinitely more to suppose that the same miracle could be repeated twice again to produce the similar systems of Jupiter and Saturn.

Thus there seems to be no alternative except supposing that at least one other body besides the sun was concerned in the birth of the planets. In 1750, Buffon imagined that the planets had been splashed out of the sun as the result of collision with a passing comet. In 1880 Bickerton propounded a somewhat similar theory except that he replaced the comet by a star. This theory has recently been revived, with further modifications, by Jeffreys. Although his views call for further discussion and critical examination, it is difficult at present to see how they can possibly be reconciled with the similarity between the systems of Jupiter and Saturn and the main system. If we grant, for the sake of argument, that a big splash formed the planets, then it seems beyond the bounds of probability that two smaller, but otherwise almost exactly similar, splashes should have occurred to create the systems of Jupiter and Saturn.

I believe I was the first, in 1901, to consider the possibility of the second body not colliding with the sun, but producing planets by tidal action. In 1904, Professors Chamberlin and Moulton independently considered the same possibility, and developed it, along lines of their own, much further than I had done. They imagined that a series of solar eruptions, such as normally appear as prominences, were so intensified by the tidal action of a passing star, that the ejected matter was projected clear of the sun's gravitational field, where it condensed into small solid bodies, which they designated as "planetesimals." These in turn underwent further aggregation and in due course formed the planets.

The scheme which they propounded seemed to me to be

open to many objections. Not only did it fail to explain why the satellite systems of Saturn and Jupiter should resemble the main planetary system; it failed to explain why satellite systems should exist at all.

Indeed I think it may fairly be said that it failed to explain why planets should exist at all. For puffs of gas such as Professors Chamberlin and Moulton imagined to condense into planetesimals would not condense at all; as soon as they got clear of the sun's atmosphere they would merely scatter into space, just as the leak of gas from a gas-burner scatters through the laboratory. Calculation shows that any body of gas will do this unless it is of enormously greater mass than the supposed planetesimals. The mutual gravitational attractions of the molecules of a mass of gas of planetesimal dimensions would be too small by a factor of several millions to produce condensation in opposition to the ordinary gas pressure resulting from the Kinetic energy of their motion.

Because the planetesimal theory seemed open to these and other fatal objections, I tried to trace out mathematically the course of events which would actually occur when a second star approached to within a specified distance of the sun, and passed on its course without collision taking place. Discarding all physical assumptions as to solar eruptions and the formation of planetesimals, I found that my own old conception of tidal action was able of itself, without any adventitious assumptions, to give a plausible account of the origin of the solar system. In this way I was led in 1916 to propound a new theory of the origin of the Solar System which was very different from that of Moulton and Chamberlin.

The researches of Roche (1850) had already shown that every large mass such as the sun is surrounded by what may properly be described as a "danger-zone." No body of moderate size can revolve permanently inside this danger-zone; it is rapidly broken up into minute pieces. It is practically certain that Saturn's moons and rings provide an instance of this process; the moons are all outside the danger-zone, but the rings are just inside, whence it is generally believed that the rings are the broken fragments of what was originally an ordinary moon of Saturn. There are good reasons for conjecturing that the system of asteroids which

surround the sun forms a second illustration of the same effect.

My mathematical investigation of the tidal action between two stars showed that this concept of a danger-zone is equally applicable when two bodies merely approach one another temporarily, and then pass on their respective courses. Two bodies which remain always at more than a certain distance from one another, merely raise tides like those which the moon raises on the earth. As their distance lessens the height of tide increases; as it increases again, the tides fall, until finally both bodies are left in their original undisturbed state. But if the two bodies approach to within a certain critical distance of each other, the whole character of these tides changes. Instead of a small elevation travelling over the surface of the disturbed body, as ocean tides travel over the surface of the earth, we have a huge mountain of gaseous matter which continually increases in height as the bodies approach, and then shoots out to form a long arm which may finally, if conditions are favourable, establish contact with the second body. The two bodies will then be joined by a filament of gas, much as the two ends of a dumb-bell are joined by the handle of the dumb-bell. Under other conditions, contact may fail to be established, and a long filament of gas will be left projecting from the primary body in the direction of the secondary body. It can be shown that this filament must inevitably, as the result of the gravitational attractions of its own molecules, condense into detached masses. We can even calculate how massive these condensations ought to be. Although no great accuracy is possible, we find that they would at least be of the same general order of magnitude as the actual planets.

Before condensation commenced, the filament would be shaped like a cigar or a torpedo; one of the two pointed ends is the peak of the tidal mountain; the other is the last thin dribble of matter which came off last as the gravitational pull of the receding star was failing. After condensation, we should expect to find the largest condensations near the centre, where the matter was originally richest, with the size of condensations tailing off at either end.

This exactly represents the present arrangement of the

planets. It explains why the central planet Jupiter is the largest, and why the sizes and the weights of the planets both show a general tendency to fall off as we recede from Jupiter in either direction. The discovery of Pluto, which is, I suppose, quite certainly less than Neptune both in size and weight, has recently provided welcome confirmation of this prediction of the theory. It is perhaps also significant that, on the whole, the densest planets are not the most massive planets, in which we might reasonably have expected to find the matter most tightly packed, but those which lie nearest to the sun, although these are of comparatively small weight. These would come from the root of the tidal mountain, and it seems probable that the heavier elements were more abundant here than at the peak of the mountain, which would be formed out of the topmost layers of the solar atmosphere. The puzzlingly low density of Saturn, only one-eighth of that of the earth, is at once explained if we suppose that Saturn was formed mainly out of the higher strata of the sun's substance.

We can, however, elaborate the theory in much greater detail than this. The planets at present move in orbits which are almost circular, but this must inevitably result from their having ploughed their way, for thousands of millions of years, through the dust and débris of space. When the planets first condensed, they would be describing quite erratic, and indeed almost random, orbits round the sun. Their orbits could hardly be expected to show any regularity beyond that of all lying in the plane of motion of the passing star which had brought them into being. Those planets which passed near enough to the sun would enter its danger-zone and be broken up in turn, just as the sun had previously been broken up by entering the danger-zone of the other star; the plane of their motion would be that containing the orbit of the planet round the sun. In this way we get a conjectural explanation of the satellite systems of the planets, of their general resemblance to the main system, as well as of the fact that their orbital planes lie mainly in the plane of the solar system.

In time the planets would cool, then liquefy, and then solidify; the largest would remain gaseous longest. Now, a

theoretical investigation of the question shows that planets which remained gaseous until after the birth of their satellites would be likely to give birth to a large number of small satellites, whereas planets which had already liquefied or solidified would be likely to give birth to a smaller number of large satellites—or possibly to no satellites at all. This at once explains a further regularity in the arrangement of the Solar System. The planets which have the greatest number of satellites are the two big central planets, Jupiter and Saturn. These have nine satellites each, all of which are very small in comparison with the planets round which they revolve. Like the main solar system, the satellite systems of Jupiter and Saturn show the characteristics to be expected in systems born out of a gaseous body. As we proceed away from these giant planets in either direction, we come to planets whose satellites are fewer in number, but larger in size relative to the sizes of their primaries. This is at once explained if we suppose that the great size of Jupiter and Saturn caused them to remain gaseous for a long time, while the smaller planets such as Mercury and Venus liquefied or solidified almost at once. The cases of transition appear to be provided by our own earth in the one direction, and by Neptune in the other; these planets each possess a single satellite which is abnormally large in comparison with the size of its primary.

We can perhaps find confirmation of this in the fact that Mars and Uranus, the two planets which come next to these as we pass toward the central planet Jupiter, are both abnormally small; we might have expected Mars to be intermediate in size between the earth and Jupiter, and Uranus to be intermediate in size between Neptune and Saturn. Now if we suppose that these two planets were the smallest of all those planets which retained their gaseous condition for long, they would suffer more than the others from the continued dissipation of their atmospheric layers into space. On this view, Mars and Uranus must be regarded as mere relics of far larger masses, and we see at once why they are abnormally small for their positions in the planetary sequence.

There are so many conjectural elements in this theory that it would be rash to claim, or even to hope, that it can in any way prove final. The highest claim I would make for it is

that it has not yet been found to suffer from insuperable objections, and that this can be said of few, if any, other hypotheses as to the origin of the Solar System.

If we accept it, we must accept also the consequences I stated at the outset. Stars are very rare objects in space, and so are very far apart, from one another—so far apart that it is very hard to imagine the sparseness of stars in space. If we leave only three particles of dust in this room, it would still be incomparably more crowded with dust than space is with stars. As a consequence stars approach one another very rarely; and it is an almost inconceivably rare event for two stars to come so close that planets are born. Planets, and so presumably life also, must be exceedingly rare in the universe.

We can regard this with satisfaction or the reverse, as we choose. Some will feel overwhelmed with a great loneliness; they will feel that it adds to the terror which overcame Pascal when he contemplated the immense voids of space.

Others will view it with satisfaction, because it adds to the relative importance of human and terrestrial life. So long as we thought of each star as the centre of a system which teemed with life, human life was a very small thing; it formed an inconceivably small fraction of the total life of the universe. The new view which I have put before you compels us to think of human life on earth as forming a comparatively large fraction of all the life of the universe. I can only leave it to you to feel pleased or the reverse, as you prefer.

Roof Landings for Autogiros. Steps are being taken to arrange for tests in taking off and landing autogiros from the roofs of large buildings in the heart of London.

This long projected type of air service from business districts of large cities to distant points is now definitely making progress at the British capitol, where officials of leading railroads, aviation experts and officials of the Cierva Autogiro Company, Ltd., have been holding a series of conferences to determine what buildings are most suitable for the purpose, and to secure permission from the British Air Ministry to lift the present restrictions regarding low flying over large cities.

Buildings being considered as possible landing fields for the new service, now first made possible by the short-run takeoff and vertical landing of the Autogiro, include the great store of Messrs. Selfridge's, that of Bush House, Aldwych, and that of the London, Midland and Scottish Railway goods station in Commercial Road, East.

R.

RESEARCH: THEORY AND PRACTICE.*

BY

WILLIS RODNEY WHITNEY, Ph.D., Sc.D., Ch.D.

Vice-President in Charge of Research, General Electric Company.

It is impossible to express the pleasure this award gives me. To be thus associated with Franklin's name and the names of those who have received similar awards is appreciated beyond expression. Franklin was our first great American scientist. He was the forerunner and guide of all our electrical engineers. He was also a plain human being, glorious in his devotion to the service of his kind. Thus his name will forever challenge reverence, whether in world politics or economics, in broad interests or narrow local levities. A capacity and a love for work and even fun, for pure experiment and helpful application—these seem to me his characteristics. Natural inquisitiveness followed by energetic application marked all his undertakings. And it was with endearing earnestness that he passed along information, particularly to the young.

What I have to say in addition to my desire to express appreciation, I, too, wish to direct especially to the very young, for I see that the younger a person is when anything is told him, the longer he may make use of it. If 70 were the age limit, it is at least five times as important to talk to a 20 year old youth as to a man of 60, for the younger man has five times as long to use it. This makes the advantage in case of youth increase in direct proportion to the age difference. Moreover, the youth is in better condition to react to new information than his elders, because he is in close touch with other youth, with its receptivity to the new and novel, whether in science or sports. A boy is much quicker at general learning at an automobile engine, an aeroplane, a new game, or a physical contest than a man. So I assume the utility of addressing youth equals the square of the age-

* Presented at the Medal Meeting held Wednesday, May 20, 1931.

differential. But this is still not enough. As we grow older we accumulate positive inhibitions, safety-first devices, delay mechanisms, inferiority complexes, etc., and thus advantages vary as the third power or higher of the youthfulness.

The guiding thought of this address is, then, to try to contribute from my experience to help those youth who aim at scientific or industrial research work, because I shall be thereby emulating the example of Benjamin Franklin. By homely illustration from his practical experiences he constantly gave wise guidance. Perhaps some youth, averse to to pure theory or higher mathematics, possesses other qualities sufficient to insure success in constructive industry. Franklin would have said he need not despair just because the theory of relativity is difficult, nor worry because favorite theories are killed one after another, provided he enjoys the excitement of the newly discovered phenomena themselves. There are wonderful realities enough for his span of life.

When Franklin experimented in electricity he had the same experiences which scientists meet today. He differentiated between interesting theory and valuable applications. He faced the problem of an electric "fluid," and early felt the need of positive and negative electric charges, as we do. He knew that electricity was fundamentally something or other, for he saw it in the lightning and in the rubbed cats' fur. He never knew just exactly what it was, but he could still make practical applications of it. We are in the same state today. We shall not live long enough to know the essence of electricity.

This condition usually confronts those who seek comprehension of essences in general. But there is always an infinite amount of usefulness often only thinly concealed in phenomena of nature. This is exposed by very simple efforts, even if the understanding of the essence itself be forever obscure. There is justification for almost any temporarily serviceable theory or hypothesis if it forces the experimenting hand, and that is the use of theory.

Franklin wrote, "In going on with these experiments, how many pretty systems do we build which we soon find ourselves obliged to destroy! If there is no other use discovered of electricity, this, however, is something consider-

able, that it may help to make vain man humble." When we consider how the theories of electricity have continued to scrape along the bottom of the oceans of useful electrical knowledge, we, too, may feel that electricity still makes vain man humble.

As a tool, electricity has improved practically every field of human endeavor except thinking. It works, listens, records, remembers, talks, but does not contemplate. There is, however, the bare possibility that our contemplation is itself some electrical process of biology.

We have now passed from the one-fluid to the two-fluid theory, and broken down the positive and negative charges into proton and electron, but we do not know what they are. We merely know some of the things which they will do for us. After a century of seeking the essence, the picture of the thing we seek is but a changing service, like a movie film. It is even now a concept of some of the recent investigators, like Dirac, that the ultimate electron is a dynamic stress, a state or thing, a polarized place, a sort of conceivable entity, but that the proton, being still less tangible, is some kind of vacancy in electronic orientation. This reminds us of Franklin's one-fluid theory, except that he pictured the positive as the excess and the negative as the vacancy. But that kind of ultimate knowledge seems indefinitely postponed. Yet there are at least two good justifications for this search, the pleasure and the results. We are so constituted that we can emulate the Creator. Imagining what the machinery may be, as distinct from how it works, we conceive of a possible apparatus with wheels, and hard round balls and waves of imaginary super-material. We are elated when we find that for a short period our creation seems to answer the limited requirements of our experience. With our new conception, which is frequently a misconception, we essay new creations. Often we produce something new and useful, but the new facts always finally force alterations of our crude mechanical conceptions. In general we are continually being forced just over the ragged edge of our powers of comprehension. I suppose this was as true when man decided how many gods of the wind there were as when the indivisible atom was thought to be the final thing in matter. In our day we have

lost sight of the old atom in the marvelous galaxy of its moving electrons. We have enjoyed many useful results and great pleasure in the serviceable pictures we have drawn, and as the pictures go on changing we get up new experiments to make use of the newly pictured things. The new wave theory of the electron will certainly serve us well, but then it will point us to a next step. It is as though we were children to whom it is necessary to give a little of the egotism of self-expression in order to make us lift the light stone under which lies Nature's next secret.

By our feeble efforts we do continually uncover valuable new utilities amid the pleasures of intricate speculations, and so justify them. The fact that the dimensions of the physical universe increase, so long as astronomers continue looking further, is paralleled every time the light of new research is applied to the essence of anything. Gravity, matter, light, thought and life still escape any ultimate analysis. But it is very characteristic and fortunate that the inquisitiveness which provides new hypotheses in reality forces research. This in turn discloses the new facts which, after they are uncovered, we then know that we need. We are quite vain when we extrapolate much with our senses. There are whole areas of truth outside the limits of our present sensitivity which cannot be expressed in terms of old sense reflexes. Franklin said, "Nor is it of much importance to us to know the manner in which Nature executes her laws; 'tis enough if we know the laws themselves." He did not imply that knowing laws was all there is to it, either; use and service were always in his mind. His kite experiment led him directly to the application of the lightning rod, which is still the principal electrical protective device.

It is not my desire to decry new theories,—they are useful —but rather to help young men to see their value. If you will examine the theory of any one subject with relation to the time of its promulgation, you will see that that theory conforms to the knowledge and belief of the period. But (in the background) there is always the continuing effort for more complete understanding and utilization—what I like to call appreciation.

With youth particularly in mind and with reference to the

application of science to industry, which is bound to be a growing field for young science students, I shall refer briefly to practical experiences or experiments of the kind which do not properly constitute scientific papers. Such things may form a pleasant part of applications of science to industrial research, however.

When we began electrical research we called ourselves the first research laboratory in our industry. Admittedly others have done research and new engineering work, but we knew of no laboratory in industry where random scientific research was going on and where publication of results was incidentally an aim. Electricity offered a very expansive field. It seemed well to combine the studies of the pure science with its applications. This becomes at the same time work and play. We first started to study scientifically electric light. Theoretically, it was then perhaps four per cent. efficient. That is, if we could learn to transform electrical energy directly into the ether vibrations of the so-called visible spectrum only, we might conserve 96 per cent. of our energy. While we went to work at once along the edges of the relevant known facts, we only did some of the obvious things, and so slowly raised the efficiency of the light. This was not so much by any new conception of what light really is, as by relatively simple, but highly interesting and inquisitive observations. Fascinated by the spectral lines and light efficiency of mercury vapor, we attacked the various vapor lamps. New facts which we learned about the mercury arc made its application as an alternating current rectifier much more successful than as a luminous source. These devices have now been used for years to supply direct current to the more modern flame arc-lamp circuits, but their greatest recent contribution lies in electric railway work, and they are now taking active part in electrification of railways here and abroad. Thus we found nature a leader easy to follow and difficult to drive. We usually wanted what she gave for our seeking, but we could seldom get exactly what we thought we wanted at the time. We wanted light. She gave us rectifiers.

While our major researches on light were under way, we attacked some apparently minor and simple problems in the porcelain plant. This work taught us, among other things,

the importance of a research laboratory's acquiring the kinds of stored knowledge already in its local atmosphere, and adding to it, if possible, from other, modern fields. Someone wanted million-ohm porcelain resistances. Nowadays countless million-ohm resistances are part of standard radio equipments, but at that time they were new and useful for certain meters. All the information we obtained through our efforts on porcelain was very interesting. It later became useful, and, after thirty years, it is still active and being applied in new ways. We learned that arts and industries contain much knowledge not recognized within the confines of any one science. Ceramics is one of the oldest industries and arts, but to the scientist it is a regular mine of new facts and tantalizing applications of modern physics and chemistry. Our megohm resistances were to be one inch long and a quarter inch in diameter. It was thought best to make them of the usual porcelain mixture impregnated with carbon. We were like kids playing with clay mixtures. The infinite variability of this simple question has always attracted me. Generally speaking, porcelain is made up of four ingredients, each of which varies a lot in itself—flint, feldspar, china clay and ball clay, in about equal proportions. Each one of these exerts some effect on the final product. Here the scientist naturally rebels, because he dislikes mixtures of so many and such crude materials. The workmen usually added unmeasured water to this mixture, and, after letting it stand a while, partially and unevenly drying, determined when it was ready to be molded by merely pinching a handful. Scientists feel that the proper moisture should be added by exact weighing, and the mixture allowed to reach equable or complete distribution, perhaps by storage in a closed space. But, to return to our megohm resistances. We carefully mixed our carbon with the porcelain ingredients, but naturally felt that the shrinkage due to the final firing must depend greatly on the moisture content, and surely the resistance depended on the final shrinkage. But with such a complex mixture, first crudely pressed into rods and then submitted to irregular air drying, and finally to uncontrolled kiln firing, one could not expect a million ohms more than any other value between zero and infinity. We learned the ceramic arts, however, and greatly appreciated their important de-

tails One by one we refined these details, and, finally, by using small, electrically heated kilns for the firing, got our process under control. We could even change the final resistance at will by the relationship between time and temperature of the final firing. This gave us confidence, so that we later coöperated with the porcelain factory in producing so-called lightning arresters. These were also porcelain and graphite mixtures, large six-inch rods having a few hundred ohms resistance. Thousands had earlier been produced in the kiln, and were mostly useless, for they had resistances varying from thousands of ohms to a few units. But by applying the same laws we had already learned, (the old facts of ceramics, figuratively speaking), we found, that we could control the final resistance of the arresters within narrow limits if we could control time and temperature of firing. This control was entirely out of the question in coal-fired kilns, so we made tubular electric furnaces, fed mechanically by an accurately timed pusher. In this way each rod passed through the identical electrical hot tube at a fixed rate, and they have been made this way now for a quarter century. All this came to my mind as illustrating the pleasure a research man may find in apparently simple things, which really are never quite simple, and it reminded me that we had used Franklin's lightning for firing millions of rods to be used in the electrical industry for keeping lightning out of electrical-power stations. We had enjoyed working very close to a field of that grand old master's.

I give these details not to record success, but to point a certain moral. In learning from those who knew porcelain, we were wise. By thus learning how we could help them, we turned the natural scorn of good, practical men for medlers, into a feeling of satisfaction that there was added to their department a new product and interesting new electrical furnaces. And that department delighted in helping us ever after. The hardest thing a young scientist in an industry has to do is to accomplish something evidently tangible. Every part of the art may be as old as ceramics, older than the pyramids. The operators may not know why they do what they do. The art may be a survival as critical as fermentation. But the young scientist in such an environment will find that the laws of physics, chemistry and electricity

are applicable at every turn. They suggest his experiments, so that the more he knows of elementary principles the more fun he has. Moreover, the interest never lags, the processes never cease changing, and new products are continually being found.

I am deliberately choosing apparently insignificant research for reference, to show that pleasure and usefulness may meet the young research man in different guises. In my early days there was great difficulty in getting electric current into the motors and out of the generators through the rotating surfaces. The contactors or so-called brushes were first made of copper. Then carbon brushes came into use. These brushes were cheap little blocks of carbon, but their defects frequently stalled long lines of electric cars in our cities. At first one might look at such a subject as quite uninteresting from a scientific standpoint, but it is capable of very interesting analysis. Carbon is not a simple thing. If there were no difference between lampblack, graphite and diamonds, there would still be the fact that carbons resulting from heating different organic materials, like wood, gums, tars, etc., all differ enormously. When we came to study the electrical properties of carbon we also found infinite variety. It is improper and impossible in this short illustrative talk to cover the subject, but here again, as in ceramics after years of useful development, we are still studying brushes in new applications, and more severe requirements are always being advanced. At present the most common railway motor brush has at least four kinds of carbon in it, and it has been first fired for a week in a carefully controlled electric furnace which must rise in temperature only about four degrees an hour; then it is fired in an ordinary porcelain kiln at the highest available temperature for another week, and then is given a day's excessively high temperature in an electric furnace. This turns it in part into a kind of graphite. I always think of that dirty work as something apparently uninviting, yet having in it just the same sort of pleasant scientific regularity and dependability that the clean, transparent, apparently simple incandescent lamp displays.

It is certain that the pleasures in store for young research men in American industries are infinite. It is also true that many of them may be found quite close to simple materials.

NEW ANTIFOGGING AGENTS IN DEVELOPERS. II.*

BY

A. P. H. TRIVELLI and E. C. JENSEN.

Introduction.—In a previous investigation of antifogging agents in developers[1] we found that 6-nitrobenziminazole, introduced by P. Wulff (U. S. Patent No. 1,696,830) as an antifogging agent in photographic emulsions, is a substance also suitable as an antifogging agent in developers to replace potassium bromide. In proper concentrations the density depression caused by this substance is so low that, with a *p*-aminophenol developer, it gives the actual densities obtained by exposures on the photographic plate or film. It is preferable to potassium bromide because of its smaller density depression without changing the speed of the investigated emulsions in the concentrations used. It was of interest to know, therefore, whether there are more substances which would behave in the same way. Antifogging agents in photographic emulsions are not necessarily always antifogging agents in developers. This seems to depend on the reaction velocity of the antifogging agent with silver halide. For this reason we started a general investigation with a rough test.

General Investigation.—For this preliminary investigation Eastman Commercial Film was used, being exposed to a high intensity tungsten lamp in a sensitometer in 20 steps with a $\sqrt{2}$ ratio of increasing exposures. Strips were developed at 20 degrees C. in a pyro developer (D-21) diluted to twice its volume in which the potassium bromide was replaced by a 1 per cent. solution of the substance under investigation. If the solubility was not high enough less concentrated solutions were used. The time of development was 4 and 12 minutes. All strips were compared with strips developed 4 and 12 minutes in a pyro developer (D-21) diluted to twice its volume and containing no antifogging agent. The fog densities were measured with a Martens

* Communication No. 440 from the Kodak Research Laboratories.

[1] *J. Frank. Inst.*, 210: 287 (1930).

densitometer. All chemicals used were from the Eastman stock of organic chemicals. A number of amino-acids were studied and comparison of the fog densities obtained showed that only cysteine hydrochloride and thiobarbituric acid were worth further investigation as antifogging agents in the developers.

In 0.1 per cent. concentration in a hydroquinone developer, thioglycollic acid caused a dense fog, and in 0.5 per cent. concentration, the fog diminished in comparison with the same developer without any antifogging agent. In 1 per cent. solution there was no development because all the silver halides of the emulsion dissolved out into the solution. During washing of the clear and slightly yellowish tinted gelatin film the silver halide precipitated out. We have made no further studies with this substance.

Photographic Material and Development.—We restricted the application of our investigation of the fog-removing qualities of cysteine hydrochloride and thiobarbituric acid to Eastman Commercial Film. Development was effected [2] in a bath the temperature of which was controlled by thermostatically operated jackets. The temperature employed was 20 degrees C. ± 0.1 degree.

The antifogging action in hydroquinone, pyrogallol, and *p*-aminophenol (hydrochloride) developers was investigated. These developers were compared with molecular equivalents and with the same amounts of sodium sulfite (Na_2SO_3) and sodium carbonate (Na_2CO_3) added. The formulas are given in Table I.

TABLE I.

Developing Formulas.

Developing Agent.	Weight of Developer.	Sodium Sulfite.	Sodium Carbonate.	Water to
Hydroquinone	5.5 gm.	50 gm.	50 gm.	1000 c.c.
Pyrogallol	3.15 gm.	50 gm.	50 gm.	1000 c.c.
P-aminophenol	7.275 gm.	50 gm.	50 gm.	1000 c.c.

The sulfur dioxide content of the sodium sulfite was determined analytically and the actual amount calculated for an

[2] Clark, W.: *Phot. J.*, 65, 76 (1925).

equivalent of 100 per cent. pure salt. The plates were developed for 3, 4, 6, 8, 10 and 12 minutes, and fixed in an acid fixing bath.

The investigations were repeated three times and the results averaged. A Martens densitometer was used to read the densities.

The Sensitometer.—The exposures were made with a non-intermittent sensitometer of 20 exposure steps progressing in a $\sqrt{2}$ ratio. The light intensity was kept constant and the time of exposure was varied. The maximum time of exposure was 724 seconds. The light source was a 500 candle power standard monoplane tungsten filament lamp, operated at 89.0 volts and 4.05 amperes to give, at a color temperature of 2900 degrees K., 0.0348 candle power intensity on the plate. The plate was 101.6 cm. from a diaphragm covered with opal glass to act as a light scatterer when placed before the light source. To keep the light intensity as constant as possible a voltage regulator, which maintained the voltage constant to within one volt was used. In this work the deviations correspond with an intensity difference of less than 6 per cent. No filters were used.

Expression of Results.—Nietz [3] expresses the density depression by the downward shift of the intersection points of the straight line portion of the H. and D. curves for different times of development. Since often the determination of this intersection point was not accurate enough, we used another expression:

$$\text{Depression} = \frac{D_0 - D_a}{D_0} \times 100,$$

in which D_0 is the density obtained with the developer that did not contain the antifogging agent, and D_a is the density obtained with the same developer with the addition of the antifogging agent, under identical conditions of exposure and development.

By plotting the depression against log E we get the depression curves for different exposures. The depression curves for different times of development were in this manner derived from the published H. and D. curves.

[3] *Theory of Development*, Monograph No. 2 from the Kodak Research Laboratories, Eastman Kodak Company.

According to Eder[4] a fog density of 0.2 is practically without any influence on the image. M. L. Dundon and J. I. Crabtree also accept this density as the maximum limit of fog allowable in practice.

In the present investigation we determined the antifogging action of cysteine hydrochloride and thiobarbituric acid in different concentrations in the developer for 12 minutes development at 20 degrees C., and chose that concentration which gives a fog density of about 0.2. This required 5 parts of cysteine hydrochloride and 2 parts of thiobarbituric acid each in 1000 c.c. developer. As an example of these determinations we give the curves obtained with the *p*-aminophenol developer in Figs. 1*A* and 1*B*. For comparison we add Fig. 1*C*, the curve of the action of 6-nitrobenziminazole in different concentrations.

Since many data were collected in this way it is out of the question to publish complete tables. It may be suggested that adequate comparison can be effected by:

(*a*) The graphic exposition of the families of H. and D. curves from 3 to 12 minutes' development.

(*b*) The graphic comparison of the depression curves for different exposures.

(*c*) The graphic exposition of the growth of fog with time of development.

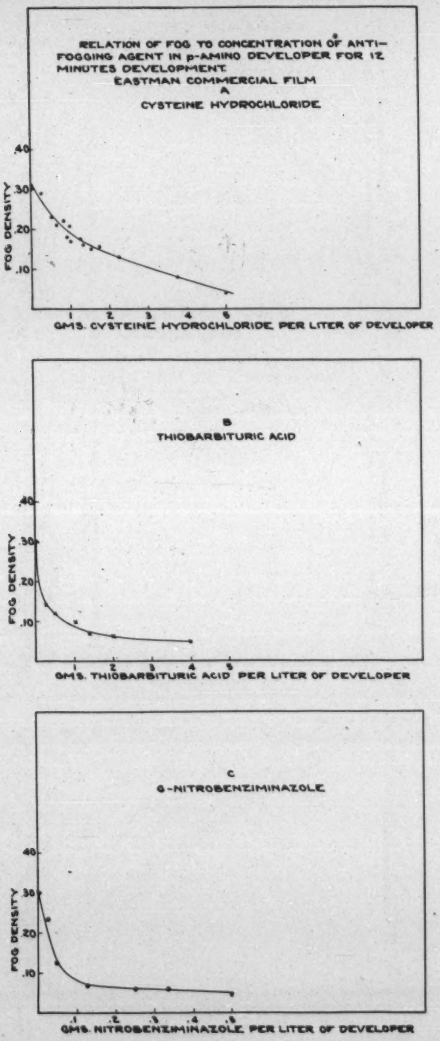
These data are sufficient for the deduction of other functions and constants; an example is the graphic exposition and comparison of the second derivates from which may be secured numerical comparison of contrasts and similar data.

The graphic exposition of the growth of gamma with time of development is omitted since, in most cases, no straight line portion of the curve could be found.

Discussion of the Results.—In Fig. 2 (*A*, *B* and *C*) are given the H. and D. curves obtained with hydroquinone developer alone and in combination with cysteine hydrochloride and with thiobarbituric acid in the concentrations as shown. All comparisons between the antifogging actions of these two substances refer only to these concentrations. No smoothing has been done to the curves in this case or in the following cases.

[4] *Eder's Handbuch der Photographie*, 3 (4): 156 (1930).

FIG. 1.


RELATION OF FOG TO CONCENTRATION OF ANTI-FOGGING AGENT IN p-AMINO DEVELOPER FOR 12 MINUTES DEVELOPMENT
EASTMAN COMMERCIAL FILM
A
CYSTEINE HYDROCHLORIDE
FOG DENSITY
.40
.30
.20
.10
1
2
3
4
5
GMS. CYSTEINE HYDROCHLORIDE PER LITER OF DEVELOPER
B
THIOBARBITURIC ACID
FOG DENSITY
.40
.30
.20
.10
1
2
3
4
5
GMS. THIOBARBITURIC ACID PER LITER OF DEVELOPER
C
6-NITROBENZIMINAZOLE
FOG DENSITY
.40
.30
.20
.10
.1
.2
.3
.4
.5
GMS. NITROBENZIMINAZOLE PER LITER OF DEVELOPER

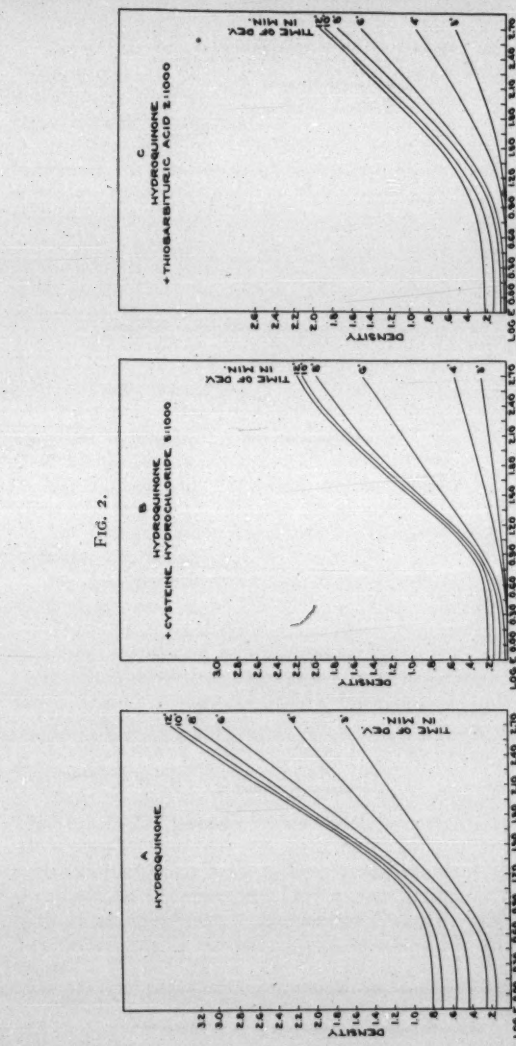

A
HYDROQUINONE
B
HYDROQUINONE
+ CYSTEINE HYDROCHLORIDE 1:1000
C
HYDROQUINONE
+ THIOBARBITURIC ACID 1:1000
TIME OF DEV. IN MIN.
DENSITY
STEP

FIG. 2.

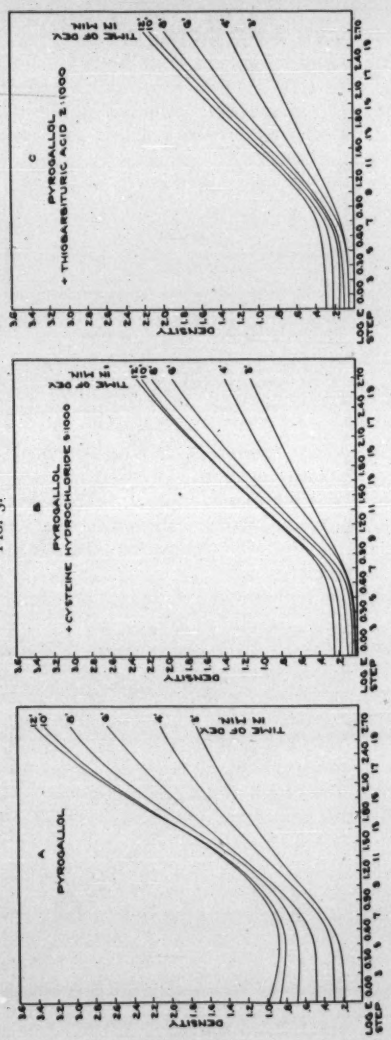

A
PYROGALLOL
B
PYROGALLOL
+ CYSTEINE HYDROCHLORIDE 1:1000
C
PYROGALLOL
+ THIOBARBITURIC ACID 1:1000
DENSITY
LOG E
STEP
TIME OF DEV. IN MIN.

FIG. 3.

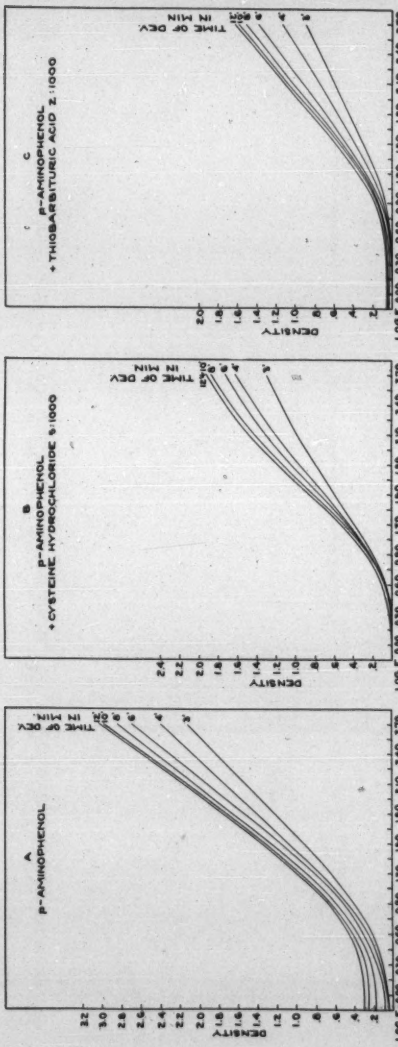

A
p-AMINOPHENOL
B
p-AMINOPHENOL
+ CYSTEINE HYDROCHLORIDE 1:1000
C
p-AMINOPHENOL
+ THIOBARBITURIC ACID 1:1000
TIME OF DEV IN MIN
DENSITY
LOG E STEP

FIG. 4.

In Fig. 3 (*A*, *B* and *C*) and Fig. 4 (*A*, *B* and *C*) are curves for comparison obtained with pyrogallol and *p*-aminophenol developers respectively.

We measured approximately the average H. and D. speed for these exposures which give values different from those obtained by daylight exposures. The results are collected in Table II. This table shows that cysteine hydrochloride and

TABLE II.

H. and D. Speed.

Developer.	Hydroquinone.	Pyrogallol.	*p*-aminophenol.
Pure developer	77	77	53
+ cysteine hydrochloride	45	53	32
+ thiobarbituric acid	16	45	23

thiobarbituric acid diminish the speed. The least decrease was with the pyro developer and the greatest with hydroquinone. Thiobarbituric acid causes a greater loss of speed than cysteine hydrochloride, which indicates that a greater depression of densities is produced with the elimination of fog. With 6-nitrobenziminazole the case is quite different as in many instances fog removal was effected without changing the speed of the photographic emulsion.

The density depression-log *E* curves for cysteine hydrochloride and thiobarbituric acid respectively are given in Figs. 5 and 6. They were derived from the corresponding H. and D. curves obtained for three different developers and previously shown. A comparison shows that the antifogging properties of both compounds are better with the hydroquinone acid and *p*-aminophenol than with the pyrogallol developers. While the density depression is highest with the hydroquinone developer the best results are obtained with the *p*-aminophenol developer.

In Figs. 7*A*, *B* and *C* are given the fog densities for three developers without and with cysteine hydrochloride and thiobarbituric acid.

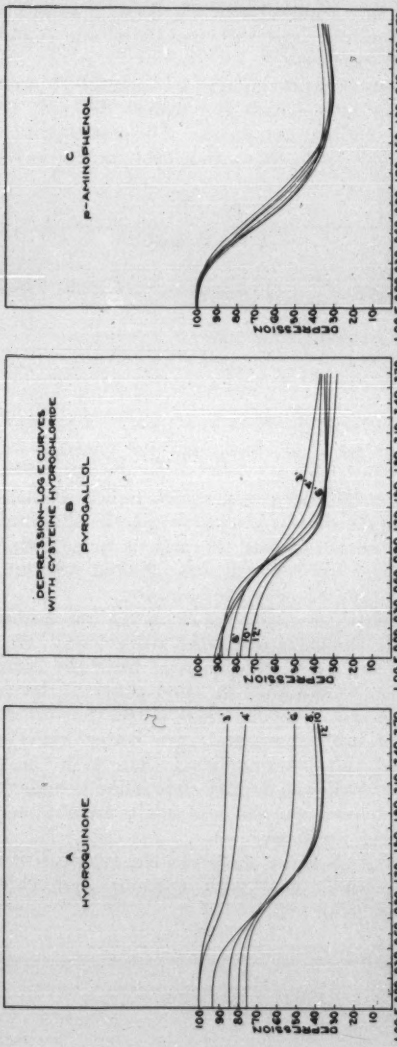

DEPRESSION-LOG E CURVES
WITH CYSTEINE HYDROCHLORIDE
A
HYDROQUINONE
B
PYROGALLOL
C
P-AMINOPHENOL
DEPRESSION
LOG E STEP

FIG. 5.

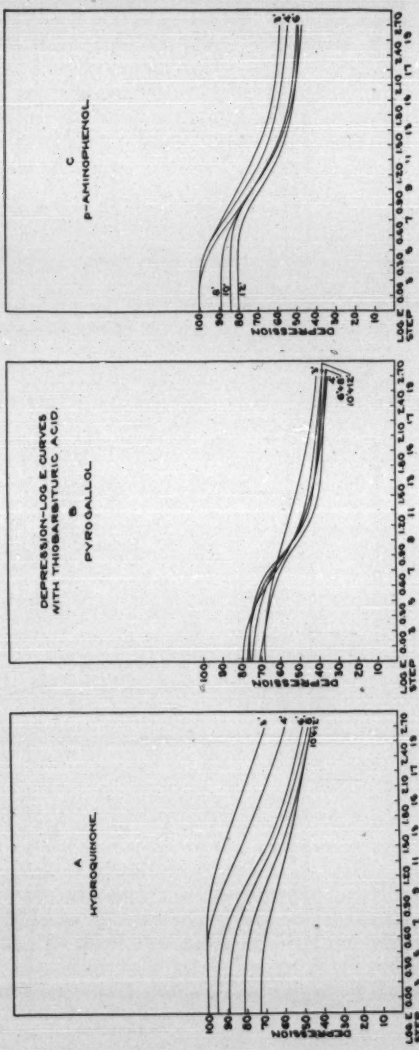

A
HYDROQUINONE
B
PYROGALLOL
C
p-AMINOPHENOL
DEPRESSION-LOG E CURVES
WITH THIOBARBITURIC ACID.
DEPRESSION
LOG E
STEP

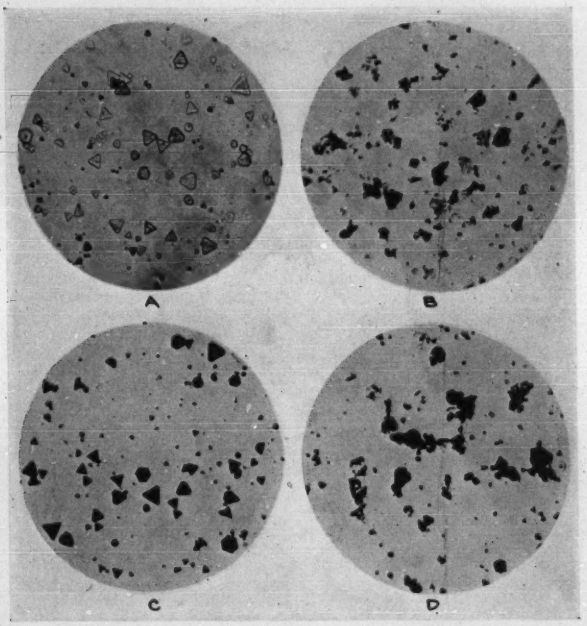
FIG. 6.

FOG-TIME OF DEVELOPMENT CURVES
A
• HYDROQUINONE
▲ " + THIOSARBITURIC ACID 2:1000
⊙ " + CYSTEINE HYDROCHLORIDE 9:1000
B
• PYROGALLOL
▲ " + THIOSARBITURIC ACID 2:1000
⊙ " + CYSTEINE HYDROCHLORIDE 9:1000
C
• p-AMINOPHENOL (HYDROCHLORIDE)
▲ " + THIOSARBITURIC ACID 2:1000
⊙ " + CYSTEINE HYDROCHLORIDE 9:1000
FOG DENSITY
DEVELOPMENT TIME (MIN.)

FIG. 7.

Microscopical Investigations.—We made a preliminary microscopical investigation of the action of antifogging agents on the developed grain and chose for that purpose a pure silver bromide emulsion with large grains as given at × 1500 magnification in Fig. 8*A*. Figure 8*B* shows this emulsion

FIG. 8.



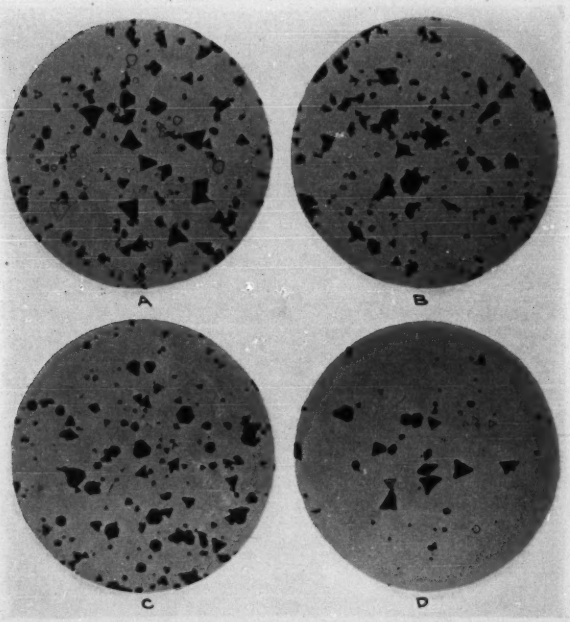
Effect of antifogging agents on the development of pure silver bromide grains. 1500 ×

after a strong exposure and development in the pure hydroquinone developer of Table I. Figure 8*C* shows the developed grain after the same development with the addition of 0.5 per cent. potassium bromide. A great effect on the size and form of the developed grains is noticeable. Figure 8*D* shows

a similar effect with the addition of 0.5 per cent. potassium iodide to the developer.

Figure 9*A* shows the effect of the addition of 1 part of 6-nitrobenziminazole to 25,000 parts of developer. Figure 9*B*

FIG. 9.



Effect of antifogging agents on the development of pure silver bromide grains. 1500 ×

shows the effect of 1 part of cysteine hydrochloride in 2000 parts of developer. Higher concentrations of cysteine hydrochloride show a solvent action on the silver bromide grains, which may explain the density depression by producing smaller developed grains. This also holds for thiobarbituric acid, which, in a dilution of 1 part in 1000 parts developer,

gave the effect shown in Fig. 9*C*. The developed grain approaches in form that of the grain obtained with hydroquinone and potassium bromide. For completeness we added Fig. 9*D* to show the effect of the addition of thioacetanilide in a dilution of 1 part in 10,000 parts of developer. These figures demonstrate the effect of the antifogging agent on the shape of the developed grain to be much stronger than in ordinary emulsions.

Conclusions.—(1) Among a series of amino-acids and other organic compounds only cysteine hydrochloride and thiobarbituric acid showed antifogging properties in the developer.

(2) The antifogging action is less than that of 6-nitrobenziminazole and produces more density depression.

(3) A preliminary microscopical investigation of the action of antifogging agents such as potassium bromide, potassium iodide, 6-nitrobenziminazole, cysteine hydrochloride, thiobarbituric acid, and thioacetanilide was made.

RESEARCH LABORATORY,
March 3, 1931.

Scientists Seek Cheap Alloy to Use in Turpentine Cups (U. S. Department of Agriculture, Press Service). The naval stores industry needs a durable and inexpensive cup for gathering turpentine gum, a cup which will neither rust nor discolor the gum. At the request of the Pine Institute of America, chemists of the U. S. Department of Agriculture have been testing cups made from various substances and of several alloys. The Bureau of Chemistry and Soils reports that several months of investigation have not yet revealed a cup material which is both inexpensive and satisfactory, but that the search will continue. Some of the alloys tested resist the chemical action of water and turpentine gum, and do not discolor the gum objectionably but these alloys are too expensive. Cups made of 26 gauge plate, the investigators say, would cost about 25 cents each, or $2,500 for a "crop" of 10,000 cups, an expense which producers can not undertake, especially at present prices for turpentine gum. The bureau will continue the studies with a view to developing a cup material that will not rust in the presence of gum and water, will not discolor the rosin collected in it, and will be cheap enough so that the operator can afford to buy.

R.

THE ECONOMIC VALUE OF MAJOR SYSTEM INTERCONNECTIONS.*

BY

NEVIN E. FUNK,

Vice-president in Charge of Engineering,
Philadelphia Electric Company.

So much has been said and written about interconnection that at first the author was somewhat loath to present this subject again, feeling that the topic had been quite completely covered. However, upon review, there seemed to be a sufficient amount of misinformation scattered through the published literature to warrant an attempt to dispel some of the misconceptions that may have arisen.

On November 19, 1926, the transmission facilities of eleven electric power utilities extending from Chicago, Ill., to Boston, Mass., were interconnected for the purpose of indicating the possibilities of maintaining synchronous operation over an extended territory. Power was not transmitted from Chicago to Boston. This was duly and correctly reported in the technical press, but the version reported in the popular press, if not carefully read, gave a very different impression of what was done. A typical example of this report is illustrated in Fig. 1, a reproduction of a clipping from one of the Philadelphia newspapers.

An item of this character captures the general public interest immediately since it has the appearance of making possible the transmission of power for distances previously impractical. However, an analysis of the facts immediately indicates the fallacy of the conclusion that commercial transmission of power has taken place.

Prior to the presentation of the economic factors controlling interconnections, the author desires to clarify the situation by analyzing the facts and discussing the conditions underlying this apparently simple case of long distance transmission.

* Presented at a meeting held Thursday, April 9, 1931.

Assume a transmission line with sufficient capacity to transmit 120,000 kw. at unity power factor and 110,000 volts a distance of 50 miles with 10 per cent. power loss. Now extend this same line from Chicago to Boston, a distance of

FIG. 1.

:R 20, 1926

1000-MILE HOOK-UP GIVES BOSTON LIGHT

Electric Power Interchanged Between New England City and Chicago; Test Is Step in Development of Single Line From Coast to Coast

BOSTON, Nov. 19 (A. P.).—Electric power was interchanged between Boston and Chicago today, the first time a test of the kind had been made over so great a distance. The experiment, which linked up the power system of the entire northeastern quarter of the country, was designed, officials said, to demonstrate the feasibility of power interchange between companies.

In addition to tieing together for demonstration purposes the largest area ever covered by a working power unit, the test, it was said, was an omen of greater "superpower" developments still to come. Robert E. Dillon, head of the regenerating department of the Boston Edison Company, described it as a step in the development of the "buss," a single huge power line running from coast to coast.

Power Crossed Seven States

Electric lamps in the Back Bay district of Boston were lighted for a time by power from Chicago, while more than a dozen light and power companies were linked in the 1000-mile hook-up.

The line of power communication ran through the States of Illinois, Indiana, down the Ohio valley into Pennsylvania, thence up to the Adirondacks and eastward through Vermont and New Hampshire down into Western Massachusetts, connecting with Boston circuits at Sudbury.

Officials explained that the test was designed simply to demonstrate the distance over which power might be sent, and was not proof of the commercial feasibility of such a hook-up. To operate such a power line economically for commercial use, Dillon said, a voltage of 500,000 would be required, which is too high to be practical at present. The longest and highest powered line at the present time is one 300 miles long, in California, using 220,000 volts.

Reproduction of a clipping from a Philadelphia newspaper.

about 1,000 miles, with the generators at Chicago supplying the line. It is possible to shortcircuit the line at Boston with a resulting input at the Chicago end of about 18,000 kv-a. Moreover, due to the reactance of the line, the energy input

would be less than 7,500 kw. and would all be used in line losses. The voltage at the receiving end of the line would be zero, since it is shortcircuited. Now suppose as a further consideration that condensers were distributed along the line to counteract the effect of inductance and their voltage graded to correspond with the resistance loss in the line, and for the sake of simplicity assume that these condensers have no power loss. Even with this special arrangement, it would only be possible to transmit 15,000 kw. with a loss of 15,000 kw. in the line. The voltage at 15,000 kw. delivered would be 55,000 volts and, by proper adjustment of the condensers required for this load condition, a receiving end voltage at no load of about 110,000 volts could be held.

As to the economics of this situation, assume that the transmission line and right-of-way costs about $36,000 per mile, or $2,400 per kw. delivered. On this investment the annual charges at 15 per cent. would be $360 per year, which, with a load factor of 50 per cent., results in a cost of over 8¢ per kw-hr. delivered for transmission charges alone, assuming generating capacity, coal, labor, stepup and stepdown substations and condensers cost nothing. Considering these the cost will be in the order of 10¢ per kw-hr. delivered.

The result, of course, is absurd as compared to the cost of generation in Boston, but no more so than much of the rather loose popular thinking that has been engendered by none too accurate reports of what has actually been accomplished.

In theory the transmission of energy from Chicago to Boston over existing transmission is carried out somewhat like this. For simplicity assume that a generating station is connected to the transmission lines at intervals of 50 miles; thus, there is one more generating station than there are 50-mile sections.

The Chicago Generating Station, designated as Station No. 1, supplies 10,000 kw. to the transmission line. Assuming 10 per cent. loss, 9,000 kw. are delivered to Station No. 2, which supplies 1,000 kw. to the line to make up the loss so that 10,000 kw. may be supplied to the second 50-mile section.

The power delivered at Generating Station No. 3 has again been reduced by losses to 9,000 kw. so that Generating Station No. 3 must supply 1,000 kw. to make up the deficit.

This process continues for each section until the last station, No. 21, which supplies the deficit of 1,000 kw. and delivers 10,000 kw. to the load.

The situation is clearly shown in Table I. Note that to deliver 10,000 kw. over the existing facilities, it is necessary to supply 20,000 kw. along the line so that out of a total of 30,000 kw. input only 10,000 kw. is delivered—almost 70 per cent. loss. Without further analysis the assumption might be made that about 30 per cent. of the Chicago energy reached Boston. This, however, is not a fact.

TABLE I.

20 Section Transmission Line 1000 Miles Long.
Power Input, Loss and Delivery.

Station Number.	Input from Station.	Loss in Transmission to Load.	Received at Load.
1	10,000	8,784	1,216
2	1,000	865	135
3	1,000	850	150
4	1,000	833	167
5	1,000	815	185
6	1,000	794	206
7	1,000	771	229
8	1,000	746	254
9	1,000	718	282
10	1,000	686	314
11	1,000	651	349
12	1,000	613	387
13	1,000	569	431
14	1,000	522	478
15	1,000	469	531
16	1,000	409	591
17	1,000	344	656
18	1,000	271	729
19	1,000	190	810
20	1,000	100	900
21	1,000	0	1,000
Total	30,000	20,000	10,000

The loss in each section is 10 per cent. of the energy supplied to this section, which consists of the energy delivered by the preceding section, plus the energy supplied by the generating station at the beginning of the section under consideration. The percentage of energy loss of the original Chicago energy can be calculated much in the same manner as the mixture of liquids. Thus the percentage of Chicago energy

delivered is 90 per cent. raised to the 20th power ($.9^{20}$ = .1216) equals about 12 per cent.

The above discussion is extremely academic since the basic assumption is that there is no load variation at any of the generating stations along the route. The usual practical load variations prevent adjustment of turbine governors with sufficient accuracy to correctly control the passing along of the transmitted energy so that while the energy may flow as desired for a short time due to fortunate circumstance, it cannot be definitely controlled, and a few minutes later may find this condition changed to one where both Chicago and Boston are supplying 10,000 kw. with the intervening load absorbing it—scarcely a practical solution of long distance power transmission.

Long distance transmission under certain conditions is an economic possibility, but it can be accomplished only by facilities specially designed to produce the result desired, not by the simple act of connecting existing equipment installed for the transmission of energy over limited distances.

Many advantages accruing from properly designed interconnections do not make as spectacular newspaper stories as an announcement of power transmission from Chicago to Boston, but the communities in the territories so interconnected will find it more to their economic advantage than the fanciful spider web of transcontinental transmission.

WHY INTERCONNECTIONS BETWEEN POWER SYSTEMS ARE DESIRABLE.

There are a large number of elements entering into the reasons for making interconnections between power systems. Some interconnections have been made where only one of these elements was a controlling factor, others where most of them have had a definite bearing in arriving at the final conclusion.

Due to local conditions, each problem is necessarily different and the relative weight of the various factors cannot be universally the same. To simplify the discussion, these elements will be presented beginning with the least complicated and proceeding to the more intricate and less generally applicable factors:

1. Increase in Service Reliability in a Given Location.
2. Increase in General Service Reliability.
3. Replacing Additional Internal Transmission Facilities.
4. Decrease in Operating Reserve at Generating Stations.
5. Increase in Operating Economy.
6. Decrease in Spare Generating Equipment.
7. Decrease in Installed Generating Capacity from Incidental Diversity.
8. Decrease in Installed Generating Capacity from Definite Diversity.

1. Increase in Service Reliability at a Given Location.

Many interconnections have been made where the transmission or distribution facilities of two utilities are supplying adjacent territories, and it is possible to connect the systems at small expense. Usually this type of connection is confined to the lower voltage distribution systems and the normal method of operation is to leave the entire connection disconnected until one of the systems experiences trouble, at which time the emergency supply is furnished from the other system by the closing of a switch. This is the least complex of all interconnections and exceeds all other types in number. The next step is the same type of interconnection applied to local transmission voltage. The result is the reinforcement of the local transmission systems of both utilities at less expense than the installation of additional transmission by both. The service reliability of the adjacent territories of both utilities is materially increased because of the additional transmission facilities serving these localities.

2. Increase in General Service Reliability.

The main high voltage transmission lines of adjacent systems may be some distance apart and the cost of connection may be quite large so that a greater benefit must result if the construction of this connection is to be economically justified.

The main transmission lines will traverse different territory and will be supplied from different generating sources. Thus by interconnection the general transmission system of the interconnecting utilities is reinforced by the additional

sources of supply available over different transmission routes.

A basic economic formula cannot be set up for items No. 1 and No. 2 since the construction cost must be equated against the value of service continuity which in itself is a variable depending upon the extent of community served and is very difficult to evaluate in dollars.

Judgment based on past experience of the service furnished to the community and its need of improvement together with the cost of caring for improved service by other means is about the only measure that can be used to determine the relative value of these interconnections.

3. Replacing Additional Internal Transmission Facilities.

As the load in a given section of a utility's (utility A) territory grows, the existing transmission facilities gradually become inadequate. This, of course, requires additional investment for new transmission lines from the utility's generating sources to the load unless another source of supply can be obtained.

A situation of this kind may make possible an interconnection with another utility (utility B) which otherwise would not be economic, since the cost of the interconnection may be more than offset by the saving in cost of the transmission line which utility A would otherwise be compelled to build.

The economics of this problem, however, is further complicated by the price at which utility B can afford to sell power to utility A. If utility A has excess generating capacity, due to the recent installation of a large unit, and utility B has only sufficient capacity to safely supply its own needs, it may be that the overall cost will have a greater influence than the possible transmission saving, and thus prevent the interconnection. If the reverse condition is true and utility B has excess capacity, the result will be favorable to the establishment of an interconnection, provided that the condition of utility B is not a transient one.

4. Decrease in Operating Reserve at Generating Stations.

To safely supply energy to a large system, it is necessary, as a minimum condition, to operate sufficient generating

units at all times that, should the largest unit fail, the remaining units in operation could adequately supply the load requirements.

By interconnecting systems, it is possible to reduce the number of units operating at any one time below that required by the systems operating independently, since there is a diversity of generating unit failures, it being extremely unlikely that a generating unit will fail in each system at the same time. If operated individually, however, each system must be prepared for the failure when it occurs, as no help is available from outside the system. As an example, assume that two independent systems, each having a load of 500,000 kw. and a maximum generating unit size of 50,000 kw., are operating 550,000 kw. of generating capacity each to protect the load. If these two systems were interconnected by an adequate transmission tie line, each system could operate 525,000 kw. of generating capacity. If a 50,000 kw. unit failed in one of the systems, the capacity of that system would be reduced to 475,000 kw. (525,000–50,000), but the other system would immediately supply 25,000 kw., so that both would be able to supply the demands of their systems. Of course, additional generating units would be put in service to safeguard the load, but the expense of operating a total of 50,000 kw. of active reserve capacity would be saved continuously.

While there would be a material saving in operating cost from an interconnection of this kind, it is problematical whether a major interconnection could be constructed with this as the only saving. However, together with other savings, this saving will make many interconnections economically possible.

5. Increase in Operating Economy.

As an initial step in the discussion of this topic, assume that there are two generating stations supplying the territory of a utility and that one of these stations has a much better economy than the other. It is evident that in general the lowest operating costs result by producing the greatest amount of energy at the more economical station, which is accomplished by assigning this station as much of the base of the

load as possible, and allowing the station with the poorer economy to carry the peaks. In passing, attention is called to the fact that this method of operation can be carried to an extreme beyond the minimum system cost, since the increment cost of the better station at the maximum load may be greater than that of the poorer station at low loads. However, this is outside of the scope of this paper.

It is unusual that base and peak load operation as referred to can be obtained with no more transmission than is required to distribute the load. Generally, additional transmission ties between generating stations are needed, or additional transmission from the base load station to some of the substations that would be supplied by the poorer generating station during the maximum load period. The operating saving is thus reduced by the annual charges on the investment in the additional transmission required.

When two systems are interconnected, although the details are more complex, the operating procedure between the systems may be considered to be much the same as between two generating stations, the most economical station in the combination being favored most and the poorest least.

If the systems are comparable in size and have had a similar load growth, the best station in each system will probably be on a parity, but the next best stations may be quite different, since the local conditions in the individual territories will undoubtedly have been different, and will have controlled the construction programs at different periods of the rapid progress in the art during the past decade.

The best of these second grade stations will be able to supply energy to both systems for more hours in the year than would be the case if operating on one system alone, because there is more load available to allocate to it.

While the second grade stations of system A may be more economical than the second grade stations of system B, the third grade stations of system B may be more economical than the third grade stations of system A. A condition thus exists where power may flow from system A to system B during some hours of the day, and the reverse flow occurs at other hours, depending upon the load variations of each system and of the combined system.

The net result will unquestionably be a reduction in production costs, but, as in the interchange between individual generating stations, the net operating savings are reduced by the annual investment charges of the interconnecting facilities. When three systems are interconnected, the operating procedure is the same as outlined for two. A few more technical difficulties may require solution, but in general the daily operation can be carried on as smoothly as the operation of two interconnected systems, or of a single system with several generating stations.

There are some conditions, where short and relatively inexpensive interconnections can be made, in which the operating savings may more than pay the annual costs of transmission, but in most cases these operating savings must be considered in conjunction with other savings to financially justify the construction of the interconnections.

6. Decrease in Spare Generating Equipment.

A system having no interconnections with its neighbors must rely upon its own facilities entirely, and must provide a sufficient amount of spare equipment to provide for the worst probable combination of load demands and unit outage.

As the number of generating stations and units within this system increases, the probability of simultaneous failures of equipment affecting the load decreases, so that the percentage of spare equipment may be reduced. As this may not be obvious to those unfamiliar with complex power distributing systems, Table II is included to indicate this situation in a very general way.

Note how the percentage of spare equipment increases when a new generating station with larger units is added to the system, and further that this percentage of spare equipment is less when the third station is established than when the second station was put in operation, although the units in the third station are double the size of those in the second station, the same relation that the units in the second station bore to those in the first station. The relative safety of the system is practically the same in every condition illustrated in Table II, since the largest unit may be put out of service without affecting the service to the system.

The argument may be correctly made that in a system supplied by 12 units the probability of the simultaneous failure of two units is greater than in a smaller system supplied by six units. As opposed to this, however, the simultaneous loss of two units in the twelve unit system in Table II would

TABLE II.

Percentage Variation of Spare Capacity.

System Load.	No. Gen. Station.	Units per Generating Station.	Spare Capacity.	Per Cent. Spare.
1000	1	2–1000 kw.	1–1000 kw.	100
2000	1	3–1000 "	1–1000 "	50
3000	1	4–1000 "	1–1000 "	33⅓
4000	2	4–1000 " 1–2000 "	2–1000 "	50
6000	2	4–1000 " 2–2000 "	2–1000 "	33⅓
8000	2	4–1000 " 3–2000 "	2–1000 "	25
10,000	2	4–1000 " 4–2000 "	2–1000 "	20
12,000	3	4–1000 " 4–2000 " 1–4000 "	2–1000 " 1–2000 "	33⅓
16,000	3	4–1000 " 4–2000 " 2–4000 "	2–1000 " 1–2000 "	25
20,000	3	4–1000 " 4–2000 " 3–4000 "	2–1000 " 1–2000 "	20
24,000	3	4–1000 " 4–2000 " 4–4000 "	2–1000 " 1–2000 "	16⅔

limit the load that could be supplied between 96 per cent. and 83 per cent. of the maximum load, while the loss of two units in the six unit system would limit the load that could be supplied between 83 per cent. and 67 per cent. of the maximum load. With the type of load variation characteristic of most

power systems, in which the daily maximum load is of short duration and lower than 80 per cent. of the annual maximum load for at least 2/3 of the year, the practical operating safety of the larger number of units is seen to be greater than that for the smaller numbers, since the capacity limitation for an outage of two units does not fall below 83 per cent. Thus the smaller percentage of spare generating equipment is justified with an increasing number of stations and units, and the same relative safety of energy supply to the system is maintained.

When two or three systems are interconnected, the number of stations and units available is immediately increased, but the probability of outage of an individual unit is unchanged; also the relative capacity of the largest unit compared to the entire system load is materially reduced. This permits a reduction in the percentage of spare capacity as compared to the total load. The practical operation of the systems is to carry a greater total load on the combined systems with the same generating capacity than could be carried by the systems individually, thus saving investment in generating station construction by delaying the construction program for generating stations after the interconnection has been made.

The saving in spare generating equipment together with the savings enumerated in the previous items will justify many high voltage interconnections.

7. Decrease in Installed Generating Capacity from Incidental Diversity.

The total load of every electric supply system is composed of a tremendous number of individual loads of varying characteristics. The sum of the maximum demands of these loads is always greater than the actual load on the system because the maxima of the individual loads are not coincident. Likewise, the maximum loads of adjacent systems will not occur simultaneously even though the loads may be of approximately the same type. Difference in sun time will affect the lighting loads, and thus the time that the maximum load occurs, controlled further by differences in industrial conditions in the adjacent territories.

This diversity between maximum system loads of a similar type always exists, but is somewhat difficult to evaluate. Primarily, experience from past performance must be relied upon, tempered by the possible effect of stormy days on the loads of both systems.

Since this diversity is the result, not of fundamental differences in the shape of the load curves, but of slight time difference of maximum system loads, it has been distinguished as incidental diversity for the purposes of this paper.

Due to incidental diversity, the total combined load of the systems will be less than the sum of the individual system loads.

Incidental diversity will thus reduce the total installed generating station capacity required to supply the combined load as compared to that required to supply the systems individually.

Ordinarily, incidental diversity alone is of insufficient magnitude to justify economically a major interconnection, but, together with the other items enumerated in the paper, will justify most interconnections.

8. Decrease in Installed Generating Capacity from Definite Diversity.

Assume that two adjacent utilities serve territories having very different load characteristics. One serves a metropolitan area with a diversified manufacturing, street railway, commercial and domestic load. The peak load of this system will usually occur about 5 P.M. in December, and result from the overlapping of the power and lighting loads.

The other utility serves a mining and industrial territory requiring very heavy power supply, while its demands for both commercial and domestic lighting are comparatively light. This results in a peak load that will occur during the day some time between 8 A.M. and 4 P.M., but usually in the morning. Any month in the year may be the peak month, but if the mine pumping load is heavy, the months of November, December and January will probably be eliminated.

Here is an entirely different type of diversity. Not only do the maximum system loads occur in different months, but

at entirely different times of the day. The combined load will be materially less than the sum of the individual loads. The diversity can be very accurately estimated and construction programs based upon it.

The economic comparison is the same as for the case of incidental diversity, but the quantity of diversity is greater and, in most cases, in itself will justify a major interconnection.

THE 220 KV. INTERCONNECTION OF THE PENNSYLVANIA POWER & LIGHT COMPANY, PUBLIC SERVICE ELECTRIC AND GAS COMPANY, AND PHILADELPHIA ELECTRIC COMPANY

The author desires to use the 220 kv. interconnection of the Pennsylvania Power & Light Company, Public Service Electric and Gas Company, and Philadelphia Electric Company as a concrete case of a major interconnection, because this single interconnection exemplifies all of the items enumerated in this paper except the first. This problem will be discussed in its entirety rather than in the order of the general items heretofore enumerated.

The extent of the interconnected territory is illustrated in Fig. 2, which also shows the major intra-company lines as well as the 220,000 volt interconnection.

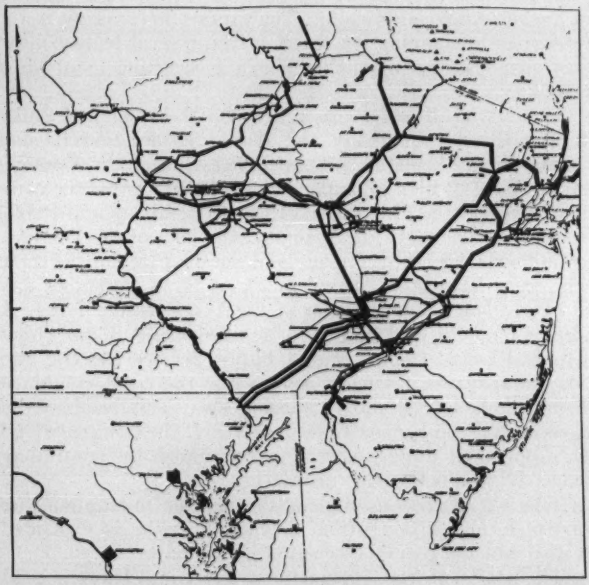
The Philadelphia Electric Company terminus of this interconnection is the Plymouth Meeting Substation near Norristown, that of the Pennsylvania Power & Light Company, the Siegfried Substation near Allentown, and that of the Public Service Electric and Gas Company, the Roseland Substation near East Orange. These substations will be connected by single circuit three phase 60 cycle steel tower transmission lines consisting of three power wires and two ground wires or their equivalent in protection.

Originally, the line from Siegfried to the Wallenpaupack Hydro Electric Station was built with three power wires only, the consensus of engineering opinion at that time being that ground wires were unnecessary on voltages as high as 220,000. Experience with this line and increasing knowledge of lightning phenomena have indicated the value of ground wires, and two ground wires have been installed on portions of the line where lightning disturbances have been more prevalent. Experimental data on lightning protection are being taken on this line, and it is anticipated that the entire line will be

equipped with two ground wires or their equivalent in protection.

All lines have been constructed except that between Roseland and the Pennsylvania-New Jersey state line, near Bushkill which it is expected will be finished this year, completing the final link in this interconnection.

FIG. 2.



Territory and interconnecting lines available to the Pennsylvania-New Jersey interconnection.

Substations ● Present 220 kv. lines ▬ Present 132 & 110 kv. lines ▬
Generating stations ▲ Proposed 220 kv. lines ▬ ▪ ▬ Present lines 66 kv. to 11 kv. ——

The territory in which the Pennsylvania Power & Light Company operates is primarily a mining, industrial and farming section of the state. It embraces nearly the entire anthracite coal field and extensive cement, slate, and steel industries are located in this section. The territory is so pre-

dominantly industrial that the load curve of the electric supply company has a daytime peak.

The territories of the Philadelphia Electric Company and the Public Service Electric and Gas Company are much alike in characteristics, being densely populated, with highly diversified and concentrated manufacturing industries. High speed, frequent transportation is a requirement. High buildings exist in numbers with the consequent lighting need in the late winter afternoon. The various power needs in the territories in combination result in the typical metropolitan load shape with a maximum demand occurring at about 5 P.M.

A material diversity exists between the combined Philadelphia Electric Company and Public Service Electric and Gas Company loads as compared with that of the Pennsylvania Power & Light Company. To illustrate this the combined loads of the Philadelphia Electric Company and Public Service Electric and Gas Company, the load of the Pennsylvania Power & Light Company and the total load of the three companies have been plotted in Fig. 3 for a December day of 1930. Note that the sum of the Pennsylvania Power & Light Company load and the combined loads of the Philadelphia Electric Company and Public Service Electric and Gas Company is 1,532,000 kw., while the total combined three system load is only 1,482,000 kw. This results from the fact that the Pennsylvania Power & Light Company load has dropped off rapidly after 2:00 P.M., and is the controlling factor in producing the diversity.

This is a concrete example of the decrease in requirements for generating capacity from definite diversity as explained in item 8 of the general discussion in this paper.

The loads of the Philadelphia Electric Company and Public Service Electric and Gas Company together with their combined load have been plotted in Fig. 4 to illustrate the incidental diversity existing between two loads of similar types. Although there is only a 2,000 kw. diversity on the day chosen, the total yearly diversity will be greater, as the peaks of each system are not simultaneous. However, the example is indicative of the comparative relation between the value of definite and incidental diversity.

FIG. 3.

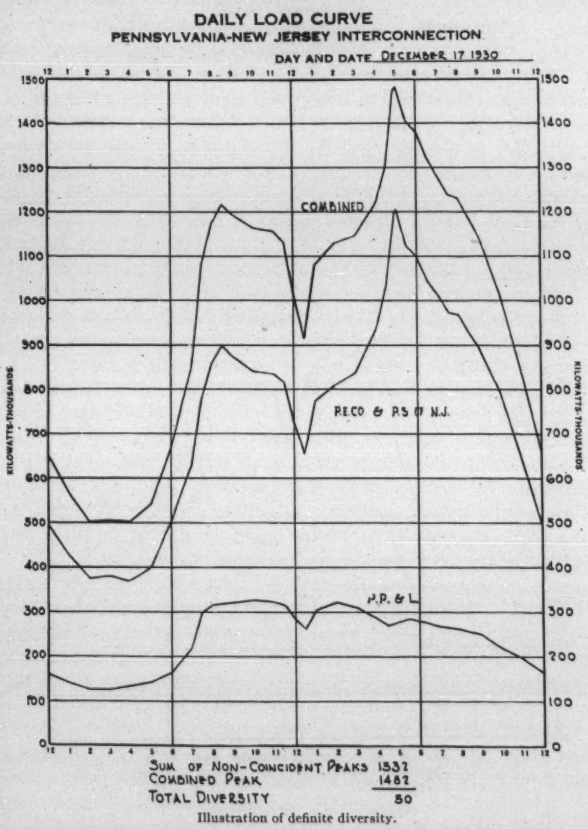


Illustration of definite diversity.

As the peak time of two loads of similar characteristics diverges, the incidental diversity increases.

This is also a concrete example of incidental diversity discussed generally in item 7.

FIG. 4.

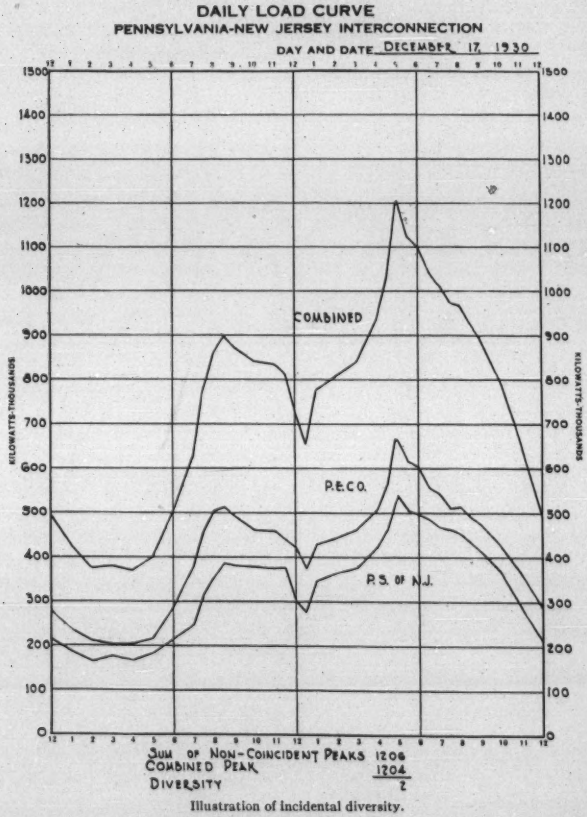


Illustration of incidental diversity.

The saving in operating costs, operating reserve and spare generating capacity installed are economies to be obtained irrespective of the saving from diversity, and are directly additive to it. The first two may be obtained as soon as the interconnecting line is constructed, the latter when loads

have increased to a value at which additional capacity would be required had the interconnection not been made. The discussions in items 4, 5 and 6 apply to the three party 220,000 volt interconnection.

Since the existing lines have been in operation, each of the systems has experienced either a major transmission or a generating station disturbance, during which the other two unaffected systems have jointly supplied as much as 90,000 kw. to the affected system until the faulty condition could be corrected—a rather outstanding example of the increase in general service reliability (item 2) of each of the systems. It is interesting to note that with a three party interconnection the system in trouble may receive about 100,000 kw. and increase the demand of each of the other systems by only 50,000 kw.

To protect each system to the same extent if operated separately, it is very probable that at least 50,000 kw. additional capacity would have been operated in each system, a total of 150,000 kw. added operating capacity, and even with this, in the case of the generating station disturbance, it is possible that some of the customers might have been affected for a short time, while with the interconnection they were not aware that any difficulty had arisen on the system.

This particular interconnection cannot concretely demonstrate the saving in internal transmission facilities (item 3) because with a growing system it is extremely difficult to paint a picture of what would have been done if the interconnection had not been made. However, the terminals of the line in each company's territory are at locations where the installation of large generating stations would have been impracticable. The substations at these terminals thus afford additional centers for distribution which, as the territorial load grows, will reduce the distance that power must be transmitted at the lower voltages.

The author desires to distinctly make the point that this discussion is confined to the effect of interconnection on the economy of the generating system alone. Its effect on the economy of distribution can only be secondary, through the establishment of additional transformation centers.

DESCRIPTION OF THE 220 KV. INTERCONNECTION.

Although rather complete descriptions of the interconnection have been given in the technical press, it is desirable to include in this paper a few views of some of the main features merely to make the story complete.

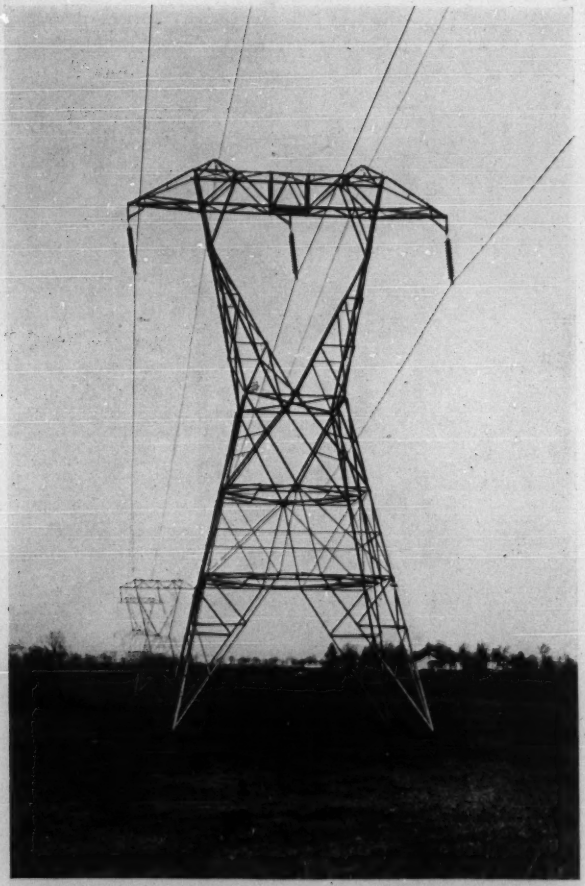
The tower construction on the main 220 kv. interconnection lines is illustrated in Figs. 5, 6, 7 and 8. The towers of the Plymouth Meeting-Siegfried line are shown in Figs. 5 and 6. The wasp-waisted tower of Fig. 5 is in the territory of the Philadelphia Electric Company, and the illustration shows very well the method of suspending the conductors and two ground wires, each of the latter being located midway between two of the conductors. This type of tower was selected because it affords a simple adaptation of the mechanics of tower design to the requirement of economy and strength. Below the waist, the tower is perfectly square, making the members on all four sides identical; thereby greatly simplifying the design. Figure 6 shows a tower in the territory of the Pennsylvania Power & Light Company, of the straight side type standard for that system. The crossarm construction is somewhat different from that of the towers in the Philadelphia Electric Company territory although the relative location of the conductors and ground wires is much the same.

The towers of the Plymouth Meeting-Roseland line are shown in Figs. 7 and 8. The type of tower in the Philadelphia Electric Company territory is illustrated in Fig. 7. These towers are basically the same as on the Plymouth Meeting-Siegfried line except that the crossarm design has been changed to bring the ground wires nearer to the outside conductors, with the expectation of better lightning protection. Figure 8 shows a tower in the territory of the Public Service Electric and Gas Company. The tower is of the straight side type, standard for that system, and the crossarm is similar to those on the Plymouth Meeting-Siegfried line.

The towers on the Conowingo-Plymouth Meeting line are similar to those in the Philadelphia Electric Company territory of the Plymouth Meeting-Siegfried line.

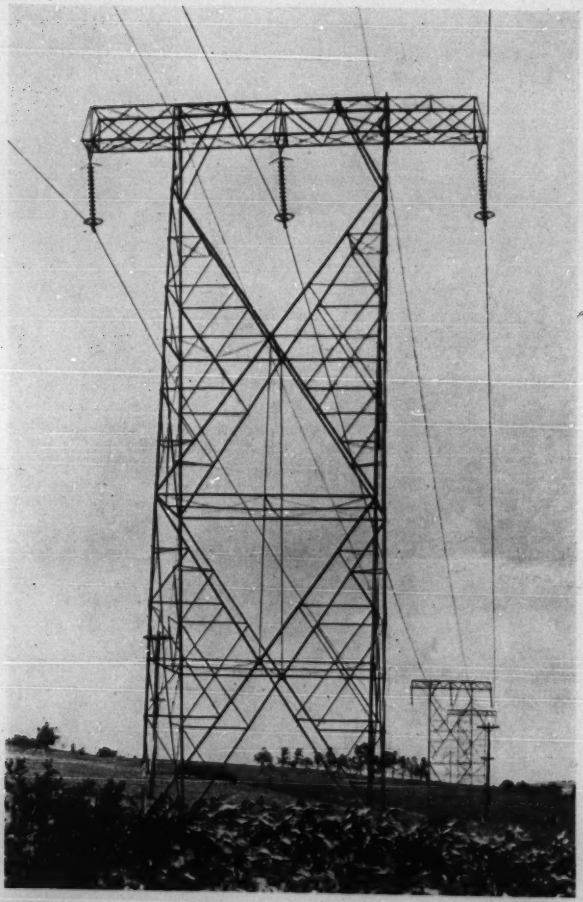
The insulators used on these lines are strings of 10 inch diameter units. Single 16 unit strings are used for suspension and three 18 unit strings in parallel are used for heavy angle

FIG. 5.



Standard tower of Plymouth Meeting-Siegfried line in Philadelphia Electric Company territory.

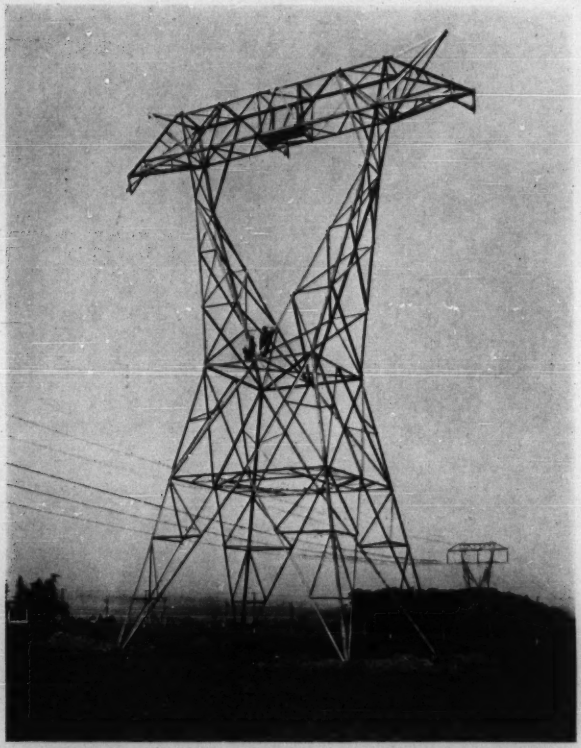
FIG. 6.



Standard tower of Plymouth Meeting-Siegfried line in Pennsylvania Power & Light Company territory.

and dead end construction. These are illustrated in Figs. 9 and 10 respectively, except that these are fourteen units per

FIG. 7.



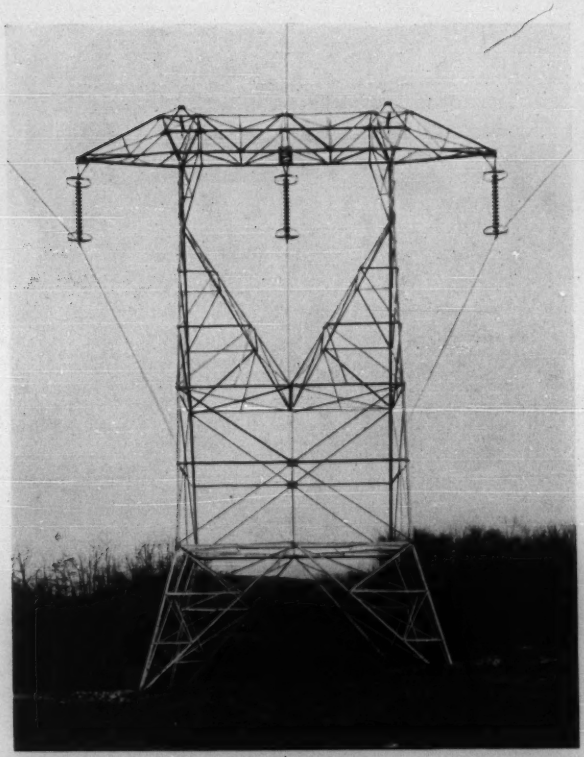
Standard tower of Plymouth Meeting-Roseland line in Philadelphia Electric Company territory.

string, a construction originally used on the Conowingo lines but later modified by adding the two units.

The type of clamp used to support the conductor is also

shown in these illustrations. The size of these insulators can be judged by comparison with the men in the picture. The

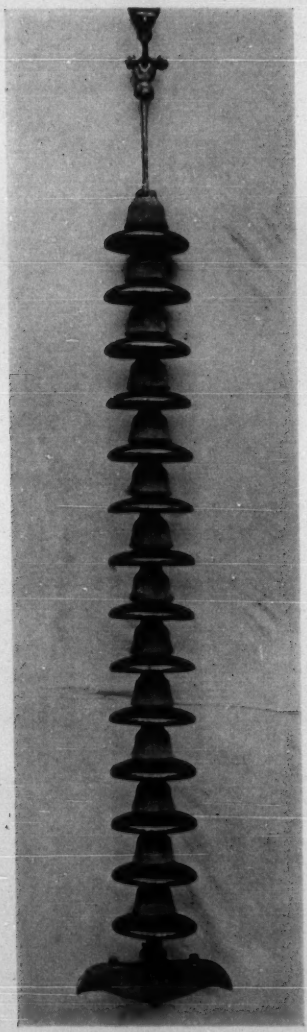
FIG. 8.



Standard tower of Plymouth Meeting-Roseland line in Public Service Electric and Gas Company territory.

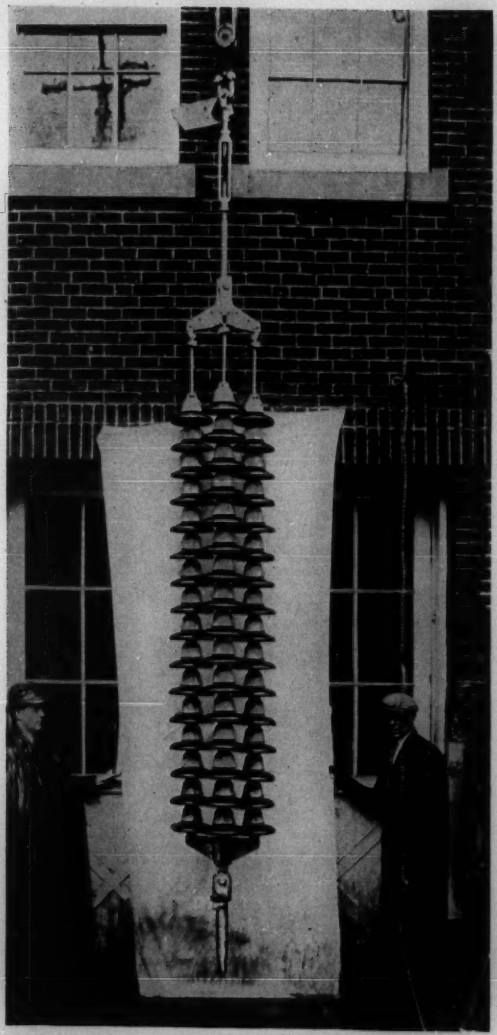
arcing rings are not shown in these illustrations but can be seen in Figs. 6 and 8. All of the lines are equipped with arcing rings except the section of the Plymouth Meeting-Siegfried line in

FIG. 9.



Single-string suspension insulator.

FIG. 10.



Triple-string strain insulator.

the Philadelphia Electric Company territory, which was left without them for experimental purposes.

An aerial view of Plymouth Meeting Substation is shown in Fig. 11. This picture was taken before the Plymouth Meeting-Roseland line was installed. Of the three towers in the background, the two on the left support the Conowingo lines and the one on the right the Seigfried line. The lightning

FIG. 11.

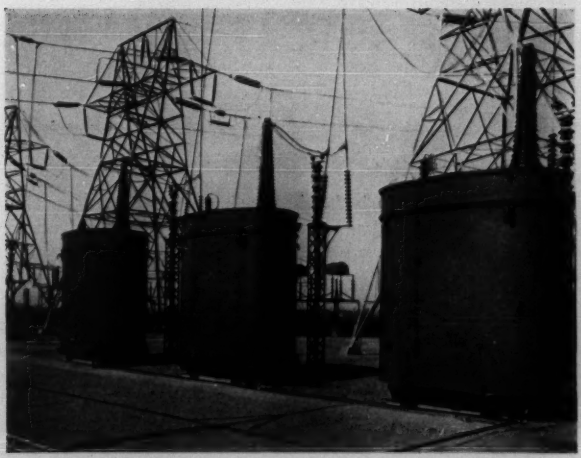
Aerial view of Plymouth Meeting Substation.

arresters appear directly behind each tower. Between these towers and the bus structure are the potential transformers on the Conowingo lines and the metering transformers on the Siegfried line. The 220 kv. bus structure and the outdoor switching equipment occupy the middle background. Between the bus structure and the buildings are the main 220 kv.-66 kv. transformers. The large building houses the synchronous condensers and the transformer repair room. The small building adjacent thereto is the operating room. To the left of the condenser house are the oil storage tanks and

FIG. 12.

Potential transformers at Plymouth Meeting Substation.

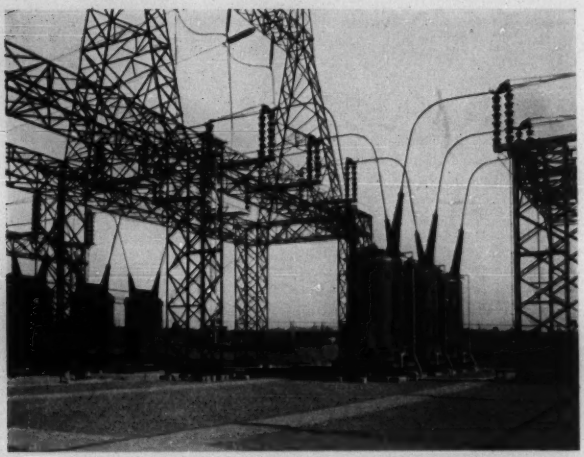
FIG. 13.



Metering transformers at Plymouth Meeting Substation.

the oil pumping and purifying house. In the foreground is the 66 kv. substation with outdoor switching equipment for the circuits to Westmoreland Substation of the Philadelphia Electric Company. The additional line from Plymouth Meeting to Roseland has been installed together with switching, metering and transformer equipment to the right of the Plymouth Meeting-Siegfried circuits, while space is provided for a third Conowingo line when required.

FIG. 14.



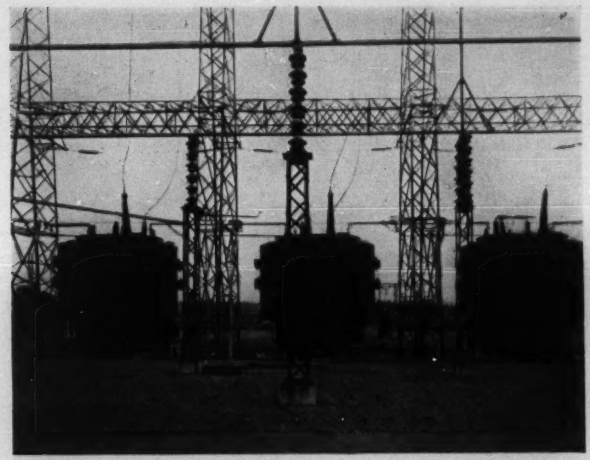
Outdoor switching equipment at Plymouth Meeting Substation.

The potential transformers on the Conowingo lines and the metering transformers on the Roseland line are shown in greater detail in Figs. 12 and 13 respectively. Methods of making connections and grounding can be distinguished.

Figure 14 is a closer view of the outdoor switching equipment. The two sets of oil switches on the Plymouth Meeting-Roseland line are shown, together with their line disconnect switches and the terminal structure for the transmission line. Methods of leading in the lines, making connections and insulating are very well illustrated.

A general view of one of the main 220 kv.-66 kv. transformer banks is shown in Fig. 15. Figure 16 gives a more detailed view of the front of one of the single-phase transformers, rated at 43,333 kv-a. at an ambient temperature of 40° C., but capable of transforming 50,000 kv-a. at the peak load period, during the winter months, due to the lower temperature. The tap changing mechanism is located in the

FIG. 15.



General view of bank of 220-66 kv. transformers at Plymouth Meeting Substation.

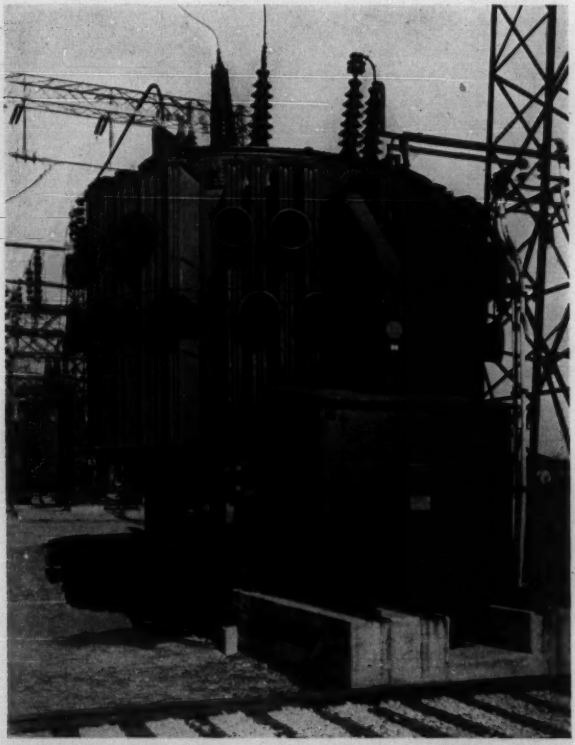
large housing in the right foreground. The transformers are oil emersed air cooled and the radiators are well illustrated. The capacity has been increased by the addition of air blowers on the radiators as shown by the circular ventilator openings.

The interior of the condenser building, with the three 30,000 kv-a. synchronous condensers, is shown in Fig. 17. In the foreground, in front of the railing, is one side of the transformer repair pit.

In order to transmit the power from Plymouth Meeting Substation to Philadelphia at Westmoreland Substation, a

distance of about 10 miles, it is necessary to pass through about five miles of closely settled territory. Arrangements

FIG. 16.

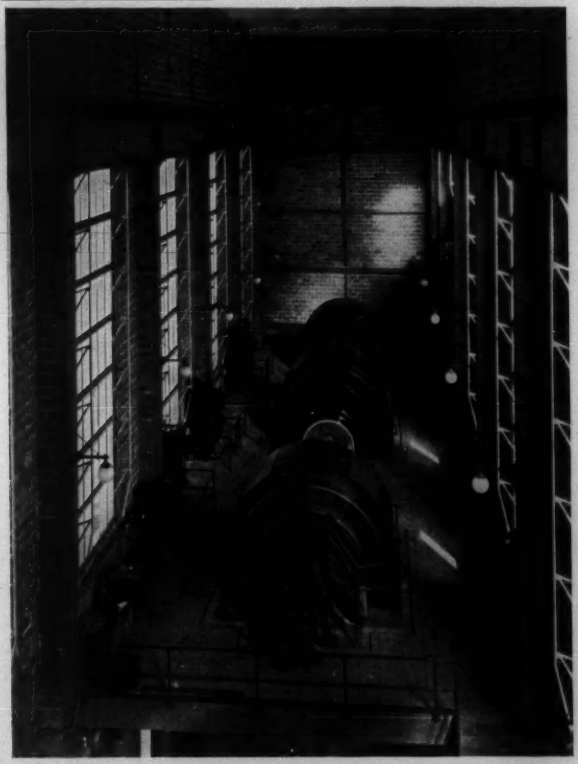


Detailed view of 220-66 kv. transformer at Plymouth Meeting Substation.

were made with the Reading Company to utilize two railroad rights-of-way in order to traverse this territory. From Plymouth Meeting to Shawmont the territory is fairly open

and undeveloped and two conventional twin-circuit tower lines were built on private right-of-way to this place; at

FIG. 17.

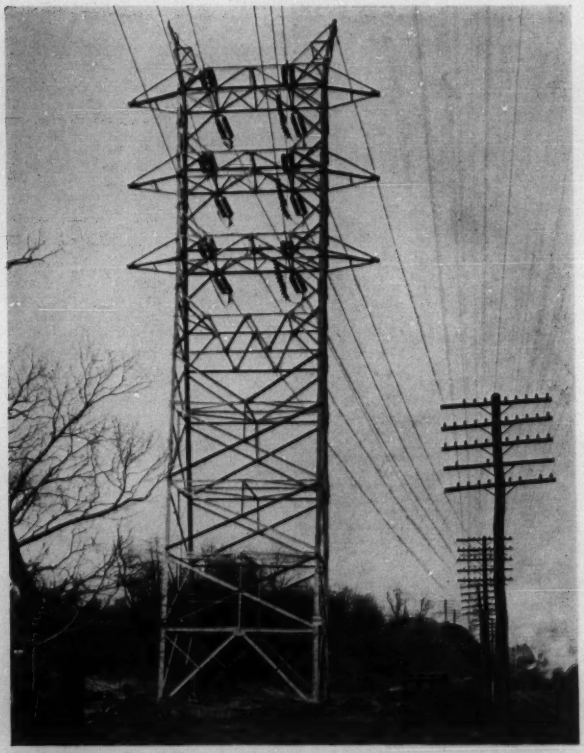


Interior of synchronous condenser building at Plymouth Meeting Substation

present only three circuits are installed. Just below Shawmont two circuits cross the Schuylkill River and are carried along the Reading Company right-of-way to near West-

moreland Substation, where they cross back and are carried to the substation. The third circuit continues down the east bank of the river, also on Reading Company right-of-way, to

FIG. 18.

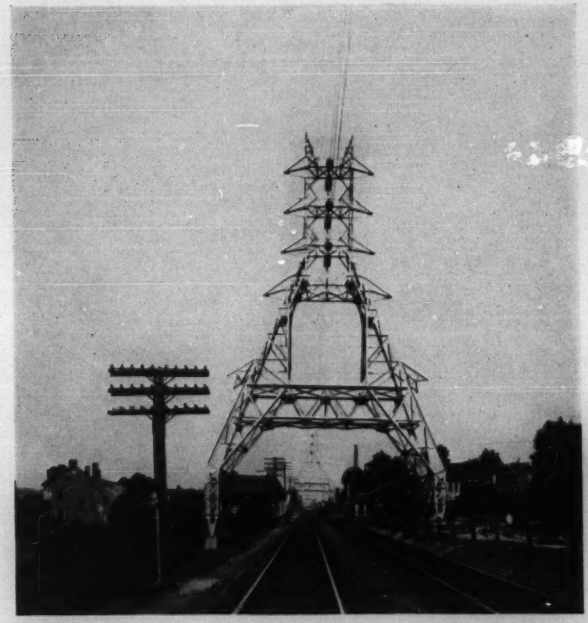


Standard tower on Reading Company overbuild.

the same substation. Many construction difficulties had to be solved due to the limits of right-of-way, etc., but the details are outside the scope of this paper.

Figure 18 shows one of the standard four circuit three phase towers on the west bank overbuild on which only two circuits have been installed to date. Figure 19 shows a three circuit three phase bridge tower on the east bank overbuild.

FIG. 19.



Bridge type tower on Reading Company overbuild.

The former tower was used where width of right-of-way permitted and the latter where the right-of-way was too narrow to accommodate the standard tower and also allow for an ultimate four track railroad. It is noticeable that all the circuit spans are dead-ended. This was done because width of right-of-way would not permit long enough crossarms

to provide clearance with standard suspension type insulators. The bridge towers on the east bank overbuild are provided with extra brackets for future 66 kv. and 36 kv. circuits for the Reading Company's Norristown branch.

The dispatching of load over the interconnection is arranged between the load dispatching offices of the three companies.

The load dispatching offices of the three companies are illustrated in Figs. 20, 21 and 22. The load dispatching board of the Pennsylvania Power & Light Company at Hazelton is shown in Fig. 20. This board is of the transmission type

FIG. 20.

Load dispatcher's board of Pennsylvania Power & Light Company at Hazelton.

used in less congested areas, where it is desirable and practicable to indicate the various transmission circuits on the board. Pilot lights are placed on the board to indicate open or closed switches and these lights are operated by a manual remote control from the operator's desk. The boards of the other two companies are of the metropolitan load type, on which it is impractical to show the transmission lines due to the congestion, and unnecessary to show them since the majority of the substation feeders are radial.

The load dispatching board of the Public Service Electric and Gas Company at Newark is shown in Fig. 21. The switches of each generating station and substation are in-

dicated in groups on the board. About one-half of the board is operated automatically from the switching equipment. The remainder of the board is manually controlled from the operator's desk.

The load dispatcher's board of the Philadelphia Electric Company is shown in Fig. 22. This board indicates the switches of the various generating stations and substations

FIG. 21.

Load dispatcher's board of Public Service Electric and Gas Company at Newark.

in groups and the main bus structures and feeders are indicated on the background between the lights. This board is also controlled from the operator's desk by remote manual control. In the center of this board are a group of meters, which show the dispatcher the frequency, load on each generating station, system load and the net load of the interconnection at Plymouth Meeting Substation. The meters have indicating and recording elements, and are the main guide in allocating load to the various generating stations. In the operation of the interconnection lines, one company usually regulates the frequency and another company controls the power flow.

FIG. 22.

Load dispatcher's board of Philadelphia Electric Company.

FIG. 23.

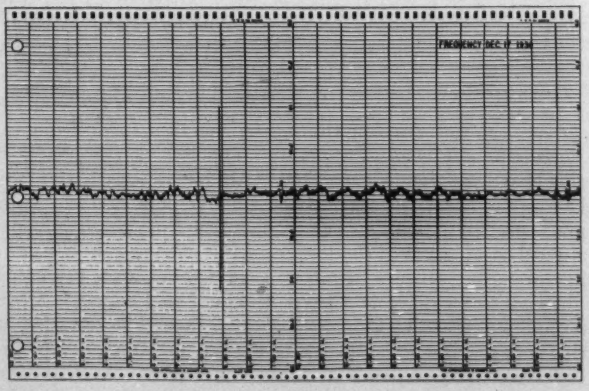


Chart from frequency meter on interconnected systems.

A chart from the frequency meter is shown in Fig. 23 and illustrates the excellent regulation that is obtained. The frequency very seldom varies more than 1/10 of a cycle, or less than 1/5 of 1 per cent. from the normal of 60 cycles. The long mark at 3 p.m. was made while replenishing the ink in the pen, and is not due to a variation in frequency.

A chart from the load meter on the interconnection lines at Plymouth Meeting is shown in Fig. 24. This chart in-

FIG. 24.

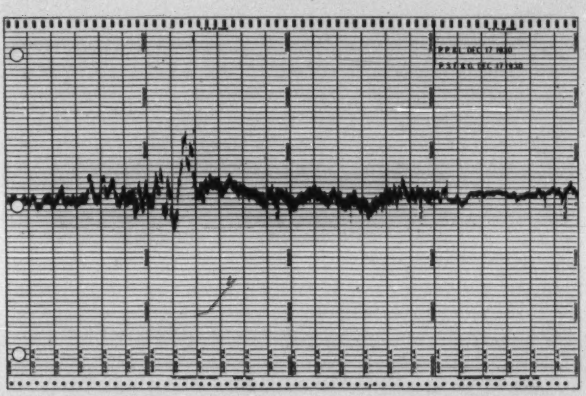


Chart showing net flow to or from the interconnection at Plymouth Meeting Substation.

dicates the net flow on the interconnection to or from the Philadelphia Electric Company. The line at the center of the chart represents zero flow. All indications above this base show flow of energy to the Philadelphia Electric Company, and all indications below show flow from that company, regardless of whether the flow is in the Siegfried or Roseland line or both. In fact, if power were flowing from Plymouth Meeting to Siegfried and from Roseland to Plymouth Meeting, the net effect at Plymouth Meeting would be recorded on this meter. A similar meter is located at Roseland on the Plymouth Meeting-Roseland line, and when the interconnection ring is completed the three terminal points will all be similarly equipped.

THE EVOLUTION OF MODERN PRINTING AND THE DISCOVERY OF MOVABLE METAL TYPE BY THE CHINESE AND KOREANS IN THE FOURTEENTH CENTURY.*

BY

JUDSON DALAND,

Professor of Medicine, Graduate School of Medicine, University of Pennsylvania, Philadelphia.

"In Europe, all books and documents were written by hand as late as the second half of the fourteenth century, when block-printing appeared" (1). For reproducing exact copies of popular short works, when needed, this was a very practicable means of printing, and continued to be used extensively until about 1525 A.D.

When the revival of learning demanded a more rapid means of producing books, printing with movable metal type came as an outgrowth of the block-printing. This was quicker and more economical for longer works, as the same type once cast could be reset over and over again.

Controversy, as to who was the inventor of movable metal type, has continued for more than four centuries, and the claim that it originated in Haarlem or Mainz is contained in many early documents, but the evidence is very conflicting. It is generally believed that movable metal type was invented by Johann Gutenberg, of Mainz, Germany, in 1450 A.D., although good evidence exists that Lourens Janszoon Coster, of Haarlem, Holland, antedated Gutenberg by several years; however, this question of priority is of little importance, as each were antedated, by more than a century, by China and Korea.

"Long before the Christian Era, the Chinese possessed a method of authentication that later developed into printing. When a contract was made, its terms were written on each end of a piece of bamboo, which was broken in two and one piece retained by each party. The matching of the broken pieces was proof of the agreement. The emperor used jade

* Presented at a meeting held Thursday, March 5, 1931.

for the same purpose. Gradually, as the imperial affairs became more complex, the pieces of jade gave place to seals. Later, documents were written on wood, upon which was placed soft, colorless clay, stamped with the impression of a seal" (2).

FIG. 1.

The original of this photograph of Coster is in Woodburn's Gallery of rare portraits, by Samuel Jones, St. Martins Lane, London, 1816, and is reproduced by the courtesy of *Harpers Magazine*.

Seals grew steadily in favor for imperial and private use, and during the Han Dynasty, 206 B.C.–220 A.D., seal cutting in jade, ivory, rhinoceros horn, precious metals and stone became a fine art.

The words "seal" and "print," are denoted by the same Chinese character.

In China, as in Europe, religion was the chief reason for

FIG. 2.

The original of this photograph of Gutenberg is in Woodburn's Gallery of Rare Portraits, by Samuel Jones, St. Martins Lane, London, 1816, and is reproduced by the courtesy of *Harpers Magazine*.

the development of printing. The Taoist and Buddhist approach to printing is founded on the seal impressions used as charms, and the Confucian- by rubbings taken from stone inscriptions.

"In 175 A.D., Ts'ai Yung (2), wrote the Confucian Classics on large tablets of stone, that the canonical works might be standardized and saved for coming generations. According

FIG. 3.

A stone inscription and a paper rubbing made from it. (Reproduced by the courtesy of the Columbia University Press.)

to the Annals of the Han Dynasty which describes this event, great numbers of scholars came to 'make exact copies' of the texts, and this has been interpreted to mean the taking of rubbings or squeezes. This was done by placing a piece of

felt over the stone inscription, and over that a piece of strong, thin, moistened paper, which was rubbed and hammered into every depression of the stone. When the paper dried, a pad of cloth was dipped into sized ink, and passed lightly and evenly over it. When the paper was finally taken off, the printing appeared white against the inked background, in the same form as the inscription itself."

According to tradition, these rubbings were taken as early as the second century, but the first known rubbing is one made during the reign of T'ai Tsung, 627–649 A.D., of the T'ang Dynasty.

In the fourth century, the Taoists made large wooden seals, containing one hundred and twenty characters, which they wore as charms when traveling in the mountains, and by impressing these charms on clay, believed they were protected from wild beasts.

About two centuries later, seal impressions were stamped on paper by means of red ink, probably made of cinnibar, and eventually caused the transition from seal impression to block-print, with the additional advantage of greater ease in reduplication. Whether the Taoists or Buddhists were responsible for this change is not known, but Carter (3), "believes that as new evidence is found, the Taoists, with their wooden charms, may prove to have been the first block-printers.

"In the sealed manuscript chamber of the Caves of the Thousand Buddhas at Tun-huang, records of early Buddhism; the earliest known block-printed book, the Diamond Sutra, of 868 A.D.; a copy of the same book taken from stone rubbings; and also evidences of the more primitive means of reduplication of which Buddhists were so fond, such as seals for seal impression on paper, stencils or pounces, and wood-cut stamps of Buddha, all of which probably led to block-printing."

The purpose of the seals was the same as those of the broken pieces of bamboo or jade, an authentication of a contract by means of the official seal, or for signing a document, which constituted a trade-mark. Later, there was another very interesting use made of seals, that of stamping the seal impression of the owner's name on things he possessed, such as paintings or works of art, much as bookplates are now used.

The seals about to be described, were collected by the author while in China, and according to Fernald (4), "may possibly date back to the twelfth century."

Seal "A" is a good example of the use of a seal for identifying objects. It is made of stone, each of the four sides measuring 5.75 x 20.5 c.m. high. Upon the sides are carved the phoenix bird, symbolic of the Empress, and also of warmth and sunshine. The two rolls hanging suspended from its bill, may represent paintings possessed by the person to whom the seal belonged: below is a peony flower, the sign of good augury. The carvings at the base of the remaining sides, probably represent fungi, symbolic of long life.

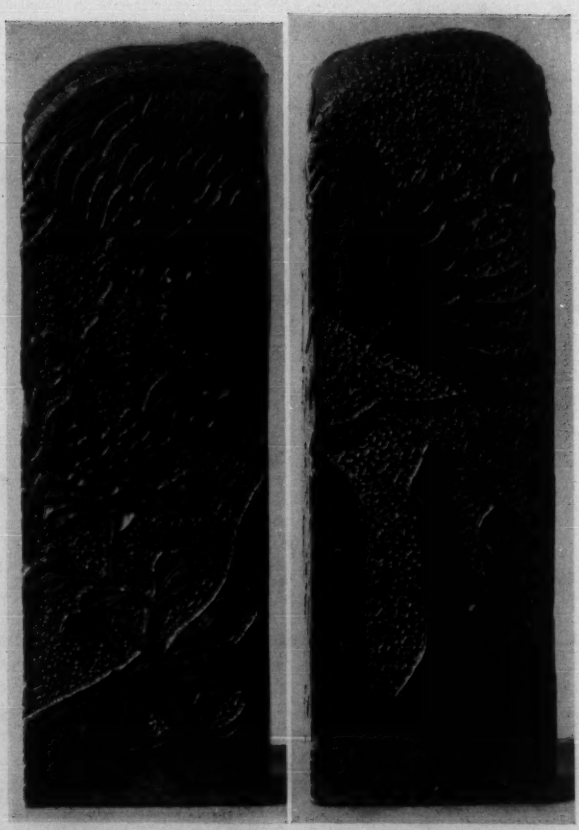
Seal "B" is approximately the same size, shape and appearance as seal "A," and on the top is carved an old pine tree, an emblem of long life, under which are little kylins, fabulous beasts, symbolic of good luck. On the opposite side is a kylin, whose head is in contact with an unknown object, and above and below are the conventional carvings representing clouds.

Seal "C" represents a carved little Fu Dog of Buddha, sitting upon a square base of stone. The base measures 3.75 x 4.75 c.m. The characters on these seals probably represent the name of the owner.

"As the Confucian Classics (3), that had been cut into stone during the Han and Tang Dynasties, were considered obsolete in the time of the Five Dynasties, Fêng Tao and his associates, wished to have revised orthodox classics made, as an incentive to the study of literature, and also as a memorial to the throne of the Central Empire. However, as there were many tasks for the administration, and a lack of resources as a result of the civil wars, Fêng Tao decided that instead of having them erected in stone, as had been the custom formerly, they should be cut in wood, after the manner of some books that had been published in the conquered province of Shu.

"The Classics and their Commentaries, were printed from wooden blocks, in one hundred and thirty volumes, from 932 to 953 A.D. Wood was used for sake of economy, with the added changes gleaned from Buddhist prints, that of cutting inscriptions in reverse, and the new manner of taking the rubbing which it required."

FIG. 4.



Seal A. 20 × 7 cm.

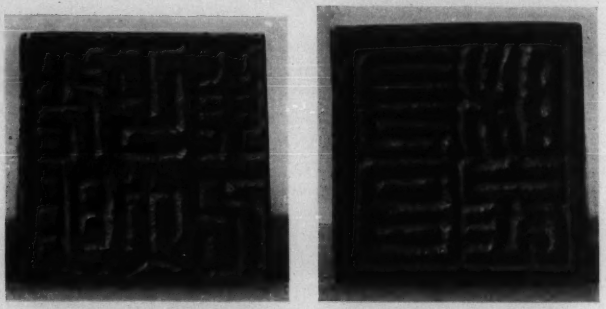
FIG. 5.

Seal B. 22 × 7.2 cm.

Though rubbings from stone played an important role in the invention of block-printing, its entire purpose was authentication of documents, and has continued to be so used to this day, while the Buddhist desire for reduplication led directly to the block-print.

The official printing of Fêng Tao's time was Confucian, its whole purpose was that of authentication of the text, and had nothing to do with making the literature more accessible to the people, so no private printing of the Classics was allowed.

FIG. 6.



The character on the bottom of seal A is to the left and that of seal B is to the right. Size 6.25 × 6.25 cm.

Along with the Confucian printing, however, the Buddhist printing was quietly progressing. "It spread to Korea (2), where an apocryphal sutra was printed in 950 A.D. About 972 A.D., the whole Buddhist canon, the Tripitaka, of more than five thousand volumes, was printed by block-prints, one of the greatest works ever published in China. The King of Korea obtained a copy in 995 A.D., and ordered a revised printing in his own country, which required fourteen years."

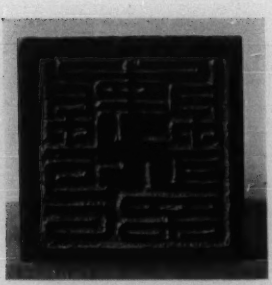
In the Sung Dynasty, 960–1280 A.D., Fêng Tao's work bore fruitful results, when block-printing became general, and public and private printing began on a large scale, and all important works were published.

"The method of making a block-print used from the time

of Fêng Tao, is as follows (5): The leaves of the book must first be written most carefully on paper, in the square form of printing characters. A piece of wood, either pear or plum, about the size of a sheet of foolscap paper, and from one-half to one inch thick, is soaked in water for some time. Then

FIG. 7.

Seal C. Fu dog of Buddha.
Size of base 3.75 × 4.75 cm.



Size of base 3.75 × 4.75 cm.

the written paper is pasted face downwards on the block, and when the paper dries, it is carefully rubbed off by wetted fingers, leaving the inked characters. The wood around the characters is all cut away with a chisel, to a depth of one-quarter of an inch, and often characters for printing are cut on both sides of the block, covered with a sheet of paper, and with one or two sweeps the impression is taken."

The advent of large scale block-printing early in the Sung Dynasty, led to various experiments in improved printing methods. "Metal blocks (3), were used instead of wood, characters standing out as on the wooden block, instead of like modern engraving.

"Of far greater consequence was the development of movable type of clay, by Pi Sheng, from 1041 to 1049 A.D. He cut separate characters in soft clay, baked them until they were hard, and when he wished to print, he put an iron frame on an iron plate covered with a sticky substance of pine resin and wax, and set his type on this plate. Then he rubbed a board over the block of type, until it was smooth enough for printing."

According to Swingle's report (1), "Wang Cheng wrote a brief account of printing with movable type, in an appendix of the Nung shu, Book of Agriculture, of 1313 A.D. In it, he mentioned wooden type, and gave a new method of making movable type by casting them of metal poured into matrices. This metal was tin, and the perforated type were strung on wires and so fastened in the compositor's form. However, neither the former type of clay nor those of tin were used very extensively, because they were not suitable for the ink then in use, and the clay and tin deteriorated rapidly."

"Wang Cheng (3), made his type of wood in much the same manner as the block-prints were made, finally sawing the block into small squares, each containing a separate character. These were measured and trimmed until each piece was exactly the same height and size, when they were ready to be set into a wooden form in columns, held firm by bamboo strips for printing.

"He also made the movable type more practicable by devising more convenient type cases, consisting of two large revolving tables divided into a great number of small boxes, to hold the many different characters of the Chinese script. The compositor sat between the tables, for quick and easy access to the huge number of characters necessary."

Chinese printing methods, as used by the Buddhists, were introduced into Korea in the tenth century, and books of the Buddhist faith were reprinted.

Though the Korean development of printing cannot be

traced as clearly as that of the Chinese, it is known that Korea had always been accustomed to draw cultural stimulus from China and hence, it is more than probable, that as Chinese books were reprinted in Korea, the improved printing methods were also adopted.

FIG. 8.

Type-setting in Korea. (Reproduced by the courtesy of *Harpers Magazine*.)

"The work of Yi Kyoo-bo (3), known as the Tong kuk Yi Sang-kuk chon chip, compiled during the reign of Ko Chong, the twenty-third Korean King of the Koryu Dynasty, in the thirteenth century, states that—'Fifty volumes of Sang Chong Ray Mun were printed,' and further, '*Using cast characters*,

twenty-eight volumes were printed, which were distributed among high officials.' The printing of the Sang Chong Ray Mun occupied eight years, from the twenty-eighth year of King Ko Chong, or from 1234 to 1241 A.D."

According to Oda's (9) interpretation of Yi Kyoo-bo's statement, "as to cast characters being used in 1234 A.D., the Koreans must have used cast metal types about three-quarters of a century before the Chinese cast types of tin." However, this interpretation may be rather broad, and it is possible that the characters may have been cast in metal blocks, which were used in China before movable types were invented.

Satow (6), in an address "On the Early History of Printing in Japan," gave the names and extracts from various early Korean books, which he claimed were printed by movable type. "One of these, the K'ung-tzu Chia-yu, dated 1317 A.D., is bound with Hsin-k'au Su wang Shih chi, dated 1324 A.D., which is printed in many folios, most of them from movable type, and a few from block-prints." This edition was given to the British Museum, by Mr. Satow, and stands as the earliest extant Korean book printed from movable types, though there is still a question as to whether it is the original or a later reprint.

In another article, Satow (7), has "translated 'post-faces' of some of the earliest of these Korean books, which give unquestionable information as to the casting of copper fonts of movable metal types. The first of these books, the Sun-tzu Shih-i Chia Chu, was printed in 1404 A.D., and has the following 'post-face' printed about five and a half years later, in 1409 A.D. 'In the second moon of the spring of the first year of Yung-lo, 1403 A.D., His Highness said to his attendants: Whoever is desirous of governing, must have a wide acquaintance with books, which alone will enable him to ascertain principles, and perfect his own character; to attain to success in regulating his conduct; in ordering his family aright; and in governing and tranquilizing the state. Our country lies beyond the seas, and but few books reach us from China. Block-cut works are apt to be imperfect, and it is moreover impossible thus to print all the books that exist. I desire to have types moulded in copper, with which to print all the books that I may get hold of, in order to make their contents

widely known. This would be of infinite advantage. But, as it would not be right to lay the burden of the cost upon the people, I and my relations, and those of my distinguished officers who take an interest in the undertaking, ought surely to be able to accomplish this.' He consequently contributed all his own private treasure, and appointed (name and title) to superintend the undertaking, and (names of officers) to carry it out. He also gave the anciently annotated copies of the Books of Poetry and History, and the Commentary of Tao belonging to the Classical School, to serve as models for the characters. They began to cast them on the 19th day of that moon, and in the space of a few months, the number had reached several hundred thousand types. The profound wisdom with which His Highness is endowed, and his enlightened goodness, led him to devote his unwearied attention to classical and historical studies during the leisure left to him by affairs of state, in order to deepen the sources from which good government springs, and to promote the beneficial influences of culture. It was his earnest desire to develop morals and religion, so as to improve them in the present age, and thus to transmit them to posterity. He consequently had these types cast, in order to print all books. May they extend to a myriad volumes in number, and be handed down during a myriad generations.' Thus vast was the design, so deep and far-reaching was the thought that inspired it. The tradition of the King's teaching shall last as long, and be as imperishable, as the Sacred Calendar."

Drake (8) states that the author of the above was Kwon Keun, famous among the greatest of Korean literati.

Yung-lo was the reigning Emperor of China, to whom it was customary to make cultural acknowledgment, but "His Highness" refers to King Tai T'sung, of Korea.

"The record of this invention is contained in 'post-faces' (7) of other books published by the Royal Printing Office, including the Li-tai Chiang Chien Po-i, which also contains two later 'post-faces,' giving an account of the following additions to the fonts already cast. The second 'post-face' was added in the latter part of 1422 A.D."

"The invention of cast types, for printing all kinds of books for transmission to posterity, is truly of infinite advan-

tage. But, at first, the types thus cast did not attain to the highest degree of perfection, and printers lamented that the work was difficult to perform. In the 11th moon of the 18th year of Yung-lo, 1420 A.D., His Highness, of his own motion, ordered his officer, Ri Chang, Vice President of the Board of Works, to cast a fresh set of types, to be very fine and small, and he commanded (name and title) to superintend and carry out the undertaking. The work was completed within the space of seven months. The printers found (these types) more convenient, and were able with them to print at the rate of more than *20* sheets a day. Our late King, Kong-tyong Tai-oang, had already done the same thing, and now His Highness, our present sovereign, has extended his work. It would be impossible to add to the perfection of the workmanship. Thus, there will be no book left unprinted, and no man who does not learn. Literature and religion will make daily progress, and the cause of morality must gain enormously. The T'ang and Han rulers, who considered the first duties of the sovereign to be finance and war, are not to be mentioned in the same day with them. It is certainly an eternal and boundless piece of fortune for this Korea of ours" (7).

The third "post-face" of the Li-tai Chien Po-i, added in 1437 A.D., follows:

"In the 7th month of the 9th year, of Hsuan-te, August 5th to September 2nd, 1434 A.D., His Highness said to Ri Chang: 'The books printed with types cast under your superintendence, are certainly very beautiful and admirable, but it is to be regretted that the characters are difficult to read, owing to their small size. It would be a fine thing to cast a fresh font from written characters of a larger size,' and he ordered him to superintend the undertaking, while (names of officials) were to carry it out. The Confucian Analects were furnished by the Classical College as models of caligraphy, and the characters which they did not contain were, by His Majesty's command, written by his officer (name). A commencement was made on the 12th day of that moon, August 16th, 1434 A.D., and in two months time over 200,000 types had been cast. On the 9th day of the 9th moon, October 11th, 1434 A.D., the printing of books was begun, and it was

found possible to print more than *40* sheets a day. The clearness and exactness of the types, made the labour twice as easy as under the old conditions. His Highness' unwearied devotion to the sacred learning, and his study of history during the leisure left to him by affairs of state, led him to wish for practical conveniences which would enable them to be widely diffused among the people, so that every one might be able to obtain the means of study. After two successive reforms, the types cast attained the greatest possible degree of beauty, and are, indeed, a treasure for this Korea of ours for all time to come" (7).

The Koreans honestly thought that the maximum amount of improvement to their movable metallic type had been attained when about *forty* sheets a day could be printed.

The advancement in printing, from so humble a beginning, is well illustrated by the following statement of Mc Lean (14), "If all the presses ran full speed continuously for *two* hours, printing the maximum size of the Evening Bulletin, the rate of production would be 625,000 copies, or *40,000,000* pages, requiring approximately *310* tons of newsprint."

Successive kings encouraged improvements in printing, causing eleven royal decrees as to the casting of new fonts of types, from 1403 to 1544 A.D. When there was a shortage of copper or bronze, eagerness for making new fonts prompted the Koreans to melt up bells from old monasteries, as well as vases and instruments belonging to various government departments and individuals; whereas, during reigns of some less philanthropic kings, when their incomes were not satisfactorily reimbursed by taxation or other sources of revenue, all fonts available were seized, melted and sold as bronze for the desired cash.

It is refreshing to learn that the Korean Kings in the 15th Century were high minded, conscientious, generous, and devoted to the welfare of their subjects, which present day rulers may well emulate. However, some of the later Kings were degenerates, supremely selfish, oppressed their subjects, and resorted to bribery, corruption and murder.

"About 1500 A.D., Song Hyon (3), described the Korean method of making movable metal bronze type. The characters which were to serve as models, were first cut from beech

wood, and then pressed into sand, which was brought from the shore and placed in a trough. These indentures formed the negative moulds, over which a cover with openings was placed, and into which the liquid bronze was poured. When the bronze cooled, it formed the separate pieces of type, which for printing were held in columns by strips of bamboo. At first, the columns were arranged on a wax plate, but later, a compositor's form was made of bamboo."

"During the reign of Song Cho, in 1592 A.D., owing to the disturbed condition of Korea, various types that had been collected, were destroyed, and later replaced by wooden types. Printing from cast metal type was revived by King Yong Cho, one hundred and eighty years later, and flourished in the reign of Chong Cho" (10).

Drake (8) asserts that it is a commonly accepted fact that in the year 1403 A.D., a font of 100,000 types was founded and put into use.

The following report was prepared for the Author, by Shyogo Oda, Director of the Government Museum, at the request of the Governor General of Korea, Baron Saito (9).

"The Chinese were probably the first to originate the art of printing. Some date its origin as far back as 50 B.C., but this can not be authenticated. The Mon Ke Pil Tam, a work of Sim Kal, during the rule of the Song Dynasty in China, makes mention of the art, and says in part: 'Some time during the Kyong Ryok era, 1041–1048 A.D., one pi Cheng made thin printing types.'

"The date of introduction into Korea of the Chinese methods of printing is not clear, but the work of a celebrated scholar, Yi Kyu Po, known as Tong Kok Yi Sang Kuk Chip, compiled during the reign of Ko Chong, the 23rd of the Koryo Dynasty, or the 13th century, remarks: 'Fifty volumes of Sang Ray Mun were printed,' and further, '*Using cast characters*, twenty-eight volumes were printed,' which were distributed among high officials." This seems to show that metallic type was in use at the time. It is also obvious that the making of type and printing had become extensively practised, for the records of Koryo describe the establishment of a Compilation Section, under whose supervision the casting of characters and printing of books were carried out, and was

still in existence in the Yi Dynasty, in 1392 A.D. "Shên Kha, a Chinese, in 1030–1093 A.D., says in his 'Meng-Ch'i-pi-t'an,' that Pi Shêng, a private person, made movable types with sticky clay. Li-Ku-Po, 1168–1241 A.D., a Korean officer of high rank, says in his 'Li-san-guk-chip,' in 1168–1241 A.D., that a book compiled by his father was printed with metallic movable types, and published during 1224–1241 A.D. This is the first description found in Korean books. The space between these two periods, is about two hundred years, during which time the Peninsula and China were in intimate relationship, and communication between the two was very active. It seems likely that movable type was first invented in China, and was introduced into Korea some time between the eleventh and thirteenth Century.

"In 1392 A.D., a compilation section was created to print books and cast types. In 1403 A.D., a similar section was created, and several hundred thousand types were cast in that year. Succeeding Kings caused to be printed a large number of books, and popular printing enterprises flourished, and it seems quite possible that the art of casting was highly developed at this time.

"It is highly regrettable that a comparative study can not be made with those of the Yi Dynasty, since neither the printing types of the Kogryo Period, nor books of the same period, printed by movable types, are available."

Oda (9) also supplied the following important data concerning the four specimens of Korean Bronze Type, illustrated by Figs. 9, 10 and 11, which was presented by the author to the Museum of The Franklin Institute, Philadelphia:

A. Wi Pu In Cha, 1434 A.D. Size 1.5 x 1.2 cm.

In the sixteenth year of King Sei Chong, *1434* A.D., over two hundred thousand types were cast, followed by one hundred and fifty thousand in the reign of King Yong Cho, 1772 A.D., and the same number in the reign of King Chong Cho, 1777 A.D. Since the characters resembled those in the handwriting of Wi Pu In, they are commonly called Wi Pu In Cha. This character "Ho," signifies Harmony.

B. Sil Lok Cha, 1455 A.D. Size 1.1 x 0.9 cm.

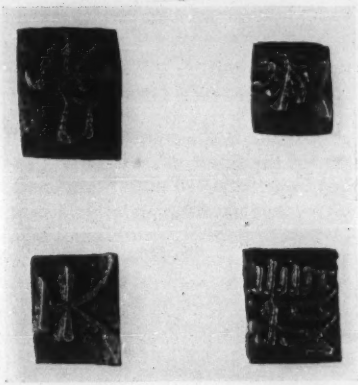
These types were first cast in the first year of King Sei Cho, 1455 A.D., and in increased quantity in the reigns of

Song Chong, 1499 A.D., and Hyong Chong, 1593 A.D. They were used in printing the annals of successive dynasties, and so the name was acquired. 150,000 types were cast. This character, "T'ien," signifies Heaven.

C. Han Ku Cha, 1700 A.D. Size 0.9 x 0.8 cm.

In the twenty-sixth year of Suk Chong, 1700 A.D., type was cast in the style used by Han Ku in writing, and again in the reigns of Chong Cho, 1782 A.D., and Chol Chong, 1858

FIG. 9.



Face of Korean bronze type.

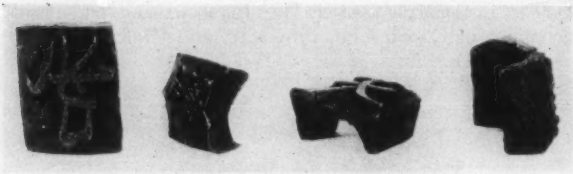
A.D., hence it is named after that calligraphic artist. It is known that 112,000 types were cast. This character, "Ai," signifies To Love.

D. Chong Ri Cha, 1792 A.D. Size 1.2 x 1.6 cm.

In the sixteenth year of King Chong Cho, 1792 A.D., three hundred thousand types in wood were cut, after the fashion of the penmanship in the Kong Feg Cha Chong, and called Sensen Cha, and four years later, the King caused five hundred thousand of them to be cast in copper, for use in printing a book known as Chong Ri Wi Ki; hence, the type came to be named after the title of the book. It is known that 428,000 types were cast. This character, "Ch'ang," signifies Guileless.

The four specimens of type are of the same general form, that is, a small rectangular piece of bronze, with the character standing out in relief, and the center of the under surface hollowed out in the form of an arch, leaving either end of the

FIG. 10.

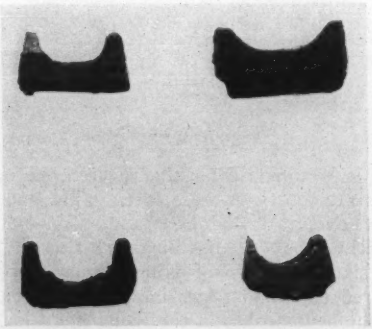


Korean type at various angles

rectangle intact. "C" is the smallest in size, and the lines of its character are of the finest moulding.

Hulbert (10), description of metal type, and the technique of the compositor, is interesting.

FIG. 11.



Korean type in profile

"Each metal type was built on the principle of the arch, being cylindrically concave on the under side, with the purpose of securing a firmer hold upon the bed of beeswax, which

constituted the 'form,' technically so-called. A shallow tray was filled with wax, and the type, after being firmly imbedded, was 'planed' in the ordinary manner. The printer, sitting cross-legged, applied liquid ink by means of a brush, after which a sheet of paper was lightly laid upon the form. A piece of felt was brushed softly across the porous paper with the right hand, and the left removed the printed page. In this way, it was possible to strike off some 1500 impressions in a day."

In 1923, after many inquiries and visits, the author discovered in the Government General Museum, at Seoul, Korea, a case in a dark corner of a corridor, containing a number of Korean bronze types, that the Director of the Museum classified as belonging to the fonts of 1403, 1420, 1424 A.D., and later.

The Korean metal type, in the American Museum of Natural History, New York, is believed by the curator, to have been made in 1408 A.D. The Museum in Leipzig contains specimens, which have not been studied by the author, but none could be found in the British Museum, London, nor in Philadelphia. The specimens in the Museum of The Franklin Institute, Philadelphia, are dated by Oda (9), as follows: Type "A" 1434; Type "B" 1455; Type "C" 1700; Type "D" 1792 A.D. It is difficult to determine the exact date of a given type, especially if many fonts of the same type were cast in different years. The number of type available for study are few, because most were destroyed by royal cupidity, theft, fire, etc.

At the request of the author, Mr. A. C. Dinkey (11), President of the Midvale Steel Co., had prepared the following report of the results of the examination of the four specimens of Korean Bronze Type, by the Research Department: "Our investigations of the various compositions of bronzes, indicates that a great variety of mixtures were used. Some of the typical analyses of the old Japanese bronzes are as follows:

	1	2	3
Cu	64.0	70.0	61.0
Zn	9.0	3.0	6.0
Sn	24.0	19.0	18.0
Pb	—	8.0	12.0
Fe	3.0	—	3.0

"Modern Japanese bronzes, for the most part, contain more lead and less tin than the ancient, and our analysis which follows would seem, therefore, to place the Korean Bronze Type 'B' in the class of antique bronzes (11 and 15).

FIG. 12.

ANALYSES OF BRONZES.

	KOREAN TYPE	ANTIQUE JAPANESE	MODERN JAPANESE
COPPER	79.45	61.0	68.25
TIN	13.20	18.0	5.47
ZINC	2.30	6.0	8.88
IRON	1.88	3.0	----
LEAD	1.66	12.0	17.06
MANGANESE	.48	----	----
ANTIMONY	----	----	.34
TOTAL	98.97%	100.%	100.%

Comparative analyses of Korean bronze type " B " with ancient and modern Japanese bronze.

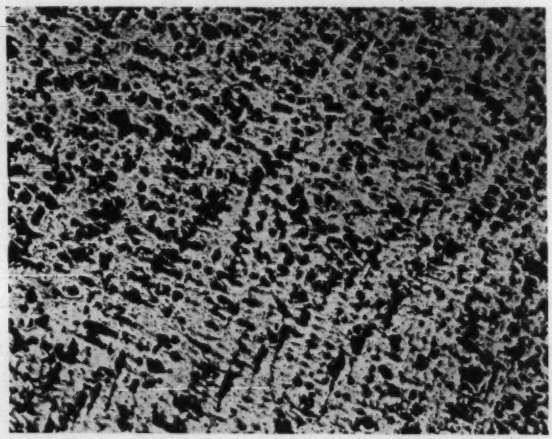
"Microscopic appearance of the metal is illustrated by the photomicrograph. It is characteristic of complex alloys of copper, tin, zinc, and lead. A dendritic cored structure is apparent. The portion examined microscopically, was cut out of Type 'B,' by means of a fine jeweler's saw. All of the cuttings were saved, and weighed 27 milligrams, and after analyzing this small sample both quantitatively and qualitatively, it was found that the type consisted of an alloy containing copper, tin, zinc, iron, lead, and manganese. After the first analysis had been made, the solid piece cut out from the corner of the type, weighing 45.3 milligrams, was analyzed with the following result:

Copper	79.45
Tin	13.20
Zinc	2.30
Iron	1.88
Lead	1.66
Manganese	.48
Total	98.97%

"Cadmium, silver, gold, platinum, bismuth, arsenic, antimony, chromium, aluminum, nickel, and barium were absent.

"All precipitates were qualitatively examined to see that they were pure, and in only one case was there found any contamination. This was in the manganese precipitation, which showed a trace of iron" (11).

FIG. 13.



Microphotograph of Korean type " B " etched by concentrated nitric acid and magnified 100 times.

This analytical study of the bronze in Korean Type "B" is a distinct addition to knowledge. The amount of copper and tin is unusually large, the quantity of lead unusually small, and the occurrence of manganese is a rarity.

It is possible that the words "copper" and "bronze" were used rather loosely by the early writers, and that in the beginning, pure copper may not have always been used in casting type, but may have been combined with other metals, as lead and tin, forming bronze.

According to Bullen (12), "Type metals are of various formulas, according to the nature and uses of various kinds of types. The metals used are lead, tin, antimony and copper;

the quantities of each metal, in the various formulas, are a trade secret."

According to Conway (13), "the parents of Sargon I, who was King of Chaldea in 3800 B.C., used bronze, which was imported into Northern Syria in 1700 B.C. The date of the appearance of bronze in China is uncertain, but nine bronze tripod cauldrons were cast in 3305 B.C."

China was the source from which both Korea and Japan obtained knowledge respecting bronze. The metals produced in China from a very early date, consisted of gold, silver, lead, copper, tin, and mercury; while in Korea, gold, copper, zinc, and iron were produced.

Bronze is singularly well suited to the use of type casting, because of its great fluidity when melted, combined with minimum contraction and maximum hardness on solidification. These properties enabled the bronze to take the impression of the mould clearly to the most minute detail.

SUMMARY.

The sequence of events in the evolution of modern printing was: Seals, Rubbings, Wooden Blocks, Clay, Copper, and Bronze Movable Type.

The discovery of printing, by movable metal type, by the Chinese, antedates Coster and Gutenberg by more than a century.

We owe an everlasting debt of gratitude to the Chinese for the discovery of printing.

The art of printing owed its inception to the need of the Chinese for reproductions of their Sacred writings.

It was discovered that reproductions could be made by "rubbings," or by Seals.

The invention of a method of transference of classic writings to blocks of wood, ushered in block-printing, marking an epoch in the History of Printing.

Block-printing and Rubbings are still employed in China, because of economy and convenience.

A most important epoch in the evolution of printing, was the making of type from clay, tin, iron and lead, and finally from copper or bronze.

Improvements were made in casting, matrices, and com-

posing, as well as other aids to typography, and also methods for rapidly securing many impressions.

The Chinese discovered printer's ink and paper, without which printing would be impossible. They also discovered the compass, gunpowder, astronomical instruments, silk, etc.

The wise and benevolent Kings of Korea early developed bronze type and printing to a high state of perfection.

Korea also invented certain kinds of paper; an iron plate warship with a ram; the first suspension bridge; the first bomb and mortar; and a pure phonetic alphabet.

The metals in modern type are similar to those in the type made by the Koreans more than five hundred years ago.

The first movable type of clay was made 1041–1048 A.D.; of tin, 1313 A.D.; of copper or bronze, prior to 1392 A.D.

Each of the four Korean Bronze Types illustrate different fonts. Type "A" was cast in *1414* A.D. The analysis of Type "B" suggests antiquity, as, for economic reasons, modern bronze usually contains *less* tin and *more* lead. The estimated age of the four Korean Bronze Types is probably correct.

Types described as copper, may have contained other metals.

Printing has advanced from about 40 sheets in one day to 40,000,000 newspaper pages in two hours.

Much praise is due Mrs. M. C. Wolfrom, in the preparation of this communication.

THE INVENTION OF PRINTING.

"Hail mystic art! which men like angels taught
To speak to eyes and paint embodied thought!
Arts, history, laws, we purchase with a look
And keep like fate, all nature in a book."

—*Anonymous.*

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MEDAL DAY MEETING.

The annual Medal Day Meeting of The Franklin Institute was held in the Hall of the Institute at three-thirty o'clock on the afternoon of Wednesday, May 20, 1931. It was also the stated monthly meeting of the Institute. It was called to order by Mr. Nathan Hayward, President.

After the approval of the minutes, the presentation of medals and Honorary Memberships was taken up. All awards which had been recommended during the present Institute year by the Committee on Science and the Arts were presented at this time.

Award of Longstreth Medal.

To Mr. Charles G. Garrard, M.E., Thorn, England. Mr. John A. Vogleson, sponsor.

The Chair recognized Mr. Vogleson.

Mr. Vogleson: "Mr. President, I have the honor to present to you, upon recommendation of the Committee on Science and the Arts, Mr. Charles G. Garrard, Mechanical Engineer, as the recipient of the Edward Longstreth Medal, 'in consideration of his invention of a means for the transmission of power as exemplified by the Garrard Speed Changer.'"

The President presented the Medal and Certificate as follows:

"In the name of The Franklin Institute, and upon the recommendation in the report just read, I, as President of the Institute, present to you the Edward Longstreth Medal."

In accepting the Medal and Certificate, Mr. Garrard expressed his thanks.

Award of Wetherill Medals.

To Mr. Thomas Tarvin Gray (deceased), Newark, New Jersey. Dr. T. K. Cleveland, sponsor.

The Chair recognized Dr. Cleveland.

Dr. Cleveland: "Mr. President, upon recommendation of

the Committee on Science and the Arts, a John Price Wetherill Medal was awarded to Mr. Thomas Tarvin Gray, former President of the Gray Industrial Laboratories, Newark, New Jersey, 'in consideration of his pioneer work in the application of a catalytic process to the refinement of gasoline.' Unhappily, Mr. Gray has died since that award. His brother, Mr. A. McDowell Gray, has come to Philadelphia to receive the Medal on behalf of the family of his brother. I present him to you."

The President presented the Medal and Certificate as follows:

"In the name of The Franklin Institute, I hand you the John Price Wetherill Medal, to be given to Mrs. Gray to hold in memory of this work, done by your brother and her husband."

Mr. Gray thanked the Institute for this award to his brother.

To Mr. Arthur J. Mason, Homewood, Illinois. Mr. Samuel Shoemaker, sponsor.

The Chair recognized Mr. Shoemaker.

Mr. Shoemaker: "Mr. President, in accordance with the findings of the Committee on Science and the Arts, the Board of Managers of The Franklin Institute has awarded to Mr. Arthur J. Mason of Homewood, Illinois, a John Price Wetherill Medal, because of 'his devising a process for the artificial curing of alfalfa that forms a valuable contribution to the art of agriculture, and of its successful application that has resulted in the production of a concentrated food for farm animals that is of the utmost importance to our economic existence.' I present Mr. Mason to you."

The President presented the Medal and Certificate as follows:

"Upon the recommendation of the Committee on Science and the Arts as just given, I, as President of The Franklin Institute, have the honor to present to you the John Price Wetherill Medal."

Mr. Mason responded: "I thank you."

To Henry M. Sutton, Edwin G. Steele and Walter L. Steele, Dallas, Texas. Mr. Owen B. Evans, sponsor.

The Chair recognized Mr. Evans.

Mr. Evans: "Mr. President, the Committee on Science and the Arts recommends that a John Price Wetherill Medal be awarded to Messrs. Henry M. Sutton, Walter L. Steele and Edwin G. Steele, of Dallas, Texas, 'in consideration of the development of old and unsuccessful methods of pneumatic separation of materials into a successful method for cleaning coal.' Unfortunately, Mr. Walter L. Steele has died during the past year and Mr. Sutton is absent from the country on business. However, I present Mr. Edwin G. Steele who has come from Texas to receive this award."

The President presented the Medal and Certificate as follows:

"Mr. Steele, upon the recommendation as just given, I, as President of The Franklin Institute, have the honor to present to you this John Price Wetherill Medal in recognition of the joint work of Mr. Henry M. Sutton, Mr. Walter L. Steele, and yourself."

Mr. Steele expressed deep appreciation on behalf of Mr. Sutton and himself for this award.

To Dr. Edward C. Wente, New York City. Mr. W. G. Ellis, sponsor.

The Chair recognized Mr. Ellis.

Mr. Ellis: "Mr. President, I have much pleasure in presenting to you Dr. Edward Christopher Wente, Research Chemist, Bell Telephone Laboratories, Inc., New York City, as the recipient of the John Price Wetherill Medal, 'in consideration of his contributions to the design and construction of condenser transmitters.'"

The President presented the Medal and Certificate as follows:

"In recognition of the work just described, I, as President of The Franklin Institute, have the honor to present to you the John Price Wetherill Medal."

Dr. Wente: "I thank you."

AWARD OF LEVY MEDAL.

To Dr. J. Stuart Foster, F.R.S.C., Montreal, Canada. Dr. Frederic Palmer, Jr., sponsor.

The Chair recognized Dr. Palmer.

Dr. Palmer: "Mr. President, the Committee on Science and the Arts, after thorough investigation, has much pleasure in recommending the award of the Louis Edward Levy Gold Medal to Dr. John Stuart Foster, for his paper in the May, 1930, issue of the JOURNAL OF THE FRANKLIN INSTITUTE, entitled, 'Some Leading Features of the Stark Effect.'"

The President presented the Medal and Certificate as follows:

"Dr. Foster, in recognition of the ability shown in the article published in the JOURNAL OF THE FRANKLIN INSTITUTE which has just been described, The Franklin Institute has awarded to you the Louis Edward Levy Gold Medal, which it is my pleasure to hand to you."

Dr. Foster thanked the Institute for this award.

AWARD OF HENDERSON MEDAL.

To Dr. Arthur Newell Talbot, Urbana, Illinois. Mr. Benjamin Franklin, sponsor.

The Chair recognized Mr. Franklin.

Mr. Franklin: "Mr. President, I am honored to be allowed to present to you Dr. Arthur Newell Talbot, Consulting Engineer and Professor Emeritus in Engineering of the University of Illinois, as the recipient of the George R. Henderson Gold Medal, 'in consideration of his practical development of the Railway Transition Spiral and for his creative guidance of American Railway Engineering Association's tests on structural and track materials for railway building and maintenance which resulted in a wide extension of the knowledge of such materials and in the promotion of safety in railroading.'"

The President presented the Medal and the Certificate as follows:

"Dr. Talbot, upon recommendation of the Committee on Science and the Arts, I have the honor to hand you this George R. Henderson Gold Medal—a medal given in memory of a

man whose ability in railroad work you and all other railroad men so well know—a man who was a most valued member of The Franklin Institute."

Dr. Talbot expressed his appreciation.

AWARD OF CLARK MEDAL.

To Mr. Daniel J. Young, Tacoma, Washington. Mr. Theobald F. Clark, sponsor.

The Chair recognized Mr. Clark.

Mr. Clark: "Mr. President, it is my privilege to introduce to you Mr. Daniel J. Young of Tacoma, Washington, who has been recommended by the Committee on Science and the Arts for the Walton Clark Gold Medal, 'in recognition of his outstanding contributions to the manufactured gas industry as embodied in his energy-conserving Back-Run Process.'"

The President presented the Medal and the Certificate as follows:

"As President of The Franklin Institute, on recommendation of the Committee on Science and the Arts, in recognition of this remarkable work which has just been described, I have the honor to present you the Walton Clark Medal, in giving which the Institute honors both you, Mr. Young, and our former president, Dr. Clark, who, you will be interested to know, has just passed his seventy-fifth birthday."

Mr. Young was highly appreciative of the honor bestowed upon him.

AWARD OF POTTS MEDAL.

To Dr. Benno Strauss, Essen, Germany. Mr. Coleman Sellers, 3d, sponsor.

The Chair recognized Mr. Sellers.

Mr. Sellers: "Mr. President, upon recommendation of our Committee on Science and the Arts, I have the honor to present to you, in absentia, Professor Doctor Benno Strauss, of Essen Germany, as the recipient of the Howard N. Potts Gold Medal, 'in consideration of the development of a more useful form of corrosion resistant metal due to its composition and its heat treatment.' In the absence of Professor Strauss, the German Consul General of New York City has been good

enough to come to receive the medal in his behalf. I present Dr. O. C. Kiep."

The President presented the Medal and Certificate as follows:

"Mr. Consul General, it is a great honor to present to you the Howard N. Potts Medal, given upon recommendation of the Committee on Science and the Arts, in recognition of the work of Dr. Benno Strauss and which I would ask you to forward to him."

In receiving the Medal Dr. Kiep said: "I thank you very much."

The Secretary of the Institute read the following cablegram which had been received from Dr. Strauss: "Regret very much having not the pleasure to be with you on Medal Day."

AWARD OF CRESSON MEDALS.

To Dr. Clinton J. Davisson and Dr. Lester H. Germer, New York City. Professor W. O. Sawtelle, sponsor.

The Chair recognized Professor Sawtelle.

Professor Sawtelle: "Mr. President, may I present Dr. Clinton Joseph Davisson and Dr. Lester Halbert Germer, Bell Telephone Laboratories, New York City, who are recommended by the Committee on Science and the Arts jointly to receive Elliott Cresson Gold Medals, 'in consideration of their pioneer work on the scattering and diffraction of electrons by crystals, and of its direct bearing on our theory of the constitution of matter.'"

The President presented the Medals and Certificates as follows:

"Dr. Davisson, Dr. Germer, it is my honor to hand you each a Cresson Medal which have been awarded to you by The Franklin Institute on the recommendation of the Committee on Science and the Arts in recognition of your joint work as just described."

Dr. Davisson and Dr. Germer: "I thank you."

To Professor Kotaro Honda, Sendai, Japan. Mr. Henry B. Allen, sponsor.

The Chair recognized Mr. Allen.

Mr. Allen: "Mr. President, the Committee on Science and

the Arts recommends the award of an Elliott Cresson Gold Medal to Professor Kotaro Honda, Director, Research Institute for Iron, Steel and other Metals, connected with the Tohoku Imperial University at Sendai, Japan, 'in consideration of the valuable contributions that he has made to our knowledge of magnetism, ferro-magnetism, and metallurgy.' In the absence of Professor Honda, I have the honor to present the First Secretary of the Japanese Embassy, who has come from Washington to receive the medal on behalf of Professor Honda."

Mr. Hayward presented the Medal and Certificate as follows:

"Mr. Secretary, it is my great privilege to hand to you, Sir, the Cresson Medal awarded to Professor Kotaro Honda, in recognition of his work on ferro-magnetism which is already having widespread results in every continent in the world."

In receiving the Medal, Mr. K. Midzuwawa said: "On behalf of Dr. Honda, I wish to thank you most sincerely for the honor and distinction. I assure you it is greatly appreciated."

The Secretary read the following cablegram: "Profound appreciation of award of Cresson Medal." The message had been sent by Dr. Honda.

To Dr. Theodore Lyman, Cambridge, Massachusetts. Dr. Winthrop R. Wright, sponsor.

The Chair recognized Dr. Wright.

Dr. Wright: "Mr. President, it is my privilege to present to you Dr. Theodore Lyman, in absentia, for many years Professor of Physics and Director of the Jefferson Physical Laboratory of Harvard University. He is recommended by the Committee on Science and the Arts to receive an Elliott Cresson Gold Medal 'in consideration of his extension of our knowledge of spectral phenomena in a region of great experimental difficulty and of high theoretical interest.'"

Mr. Hayward: "We got word at the last minute that Dr. Lyman was seriously ill with peritonitis. I am asking the Secretary to forward to him this medal and bear from all of us the most sincere hope that he will soon be well and back at his duties."

Dr. McClenahan: "I will make every effort to see that the medal and certificate are delivered to Dr. Lyman. I have to report that a message has already gone to him in the name of this audience, to express our sympathy, our regret and our good wishes."

AWARD OF FRANKLIN MEDALS.

To Dr. Willis Rodney Whitney, Schenectady, New York. Dr. James Barnes, sponsor.

The Chair recognized Dr. Barnes.

Dr. Barnes: "Mr. President: The Board of Managers of The Franklin Institute on the recommendation of its Committee on Science and the Arts is unanimously of the opinion that a Franklin Medal be awarded to Doctor Willis Rodney Whitney, 'in recognition of his valuable contributions to industrial chemistry, and of his signal success as organizer and director of the greatly productive research laboratory of the General Electric Company, a success due in large part to his appreciation of the potential value of pure research in invention and industry, to his judgment of men and to his generosity in dealing with them.'

"Doctor Whitney was born in Jamestown, New York, in 1868. He received his scientific education at the Massachusetts Institute of Technology and at Leipzig University where he earned the degree of Doctor of Philosophy. For many years he served well his Alma Mater as investigator and teacher in the Chemistry Department—occupying all the grades from Assistant Instructor to Assistant Professor. In 1900, at the age of thirty-two, he was appointed to his present position as Director of the Research Laboratory of the General Electric Company.

"He is a member of the United States Naval Consulting Board, of the Advisory Committee of the Bureau of Standards and of the National Research Council. He is the recipient of the Willard Gibbs Medal, the Chandler Medal and the Perkin Medal which are the highest honors American chemists can pay to one of their profession.

"Doctor Whitney is the author of numerous articles of much scientific value and he has been granted many patents.

But most important of all, he has built up a research organization which is recognized not only in this country but abroad as second to none. There, literally thousands of scientific problems have been attacked, chiefly at his suggestion and under his direction. The results of these investigations have yielded not only facts of scientific value but they have been applied in the development of devices which have made life safer and the earth a happier and healthier place to live on. A few of these devices may be mentioned— the hot cathode x-ray bulb, the gas filled tungsten filament lamp, the atomic hydrogen welding torch, the condensation vacuum pump and the thyratron.

"Doctor Whitney is a tireless worker with a thorough knowledge of the laws of Nature and possesses the happy faculty of being able to guide that group of geniuses who work with him in Schenectady.

"This man The Franklin Institute is happy to honor with its badge of Knighthood, The Franklin Medal, and Certificate of Honorary Membership in The Franklin Institute. Therefore, Mr. President, I have the honor and pleasure of presenting to you this distinguished experimental scientist, Doctor Willis R. Whitney."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership, as follows:

"Dr Whitney, in recognition of your work in research and in further recognition of your leadership of the many great research students who have carried on their investigations under your inspiring guidance, The Franklin Institute awards to you the Franklin Medal which is the highest award in its power to confer. By authority vested in me as President of the Institute, I have the honor to present to you this medal and with it this Certificate of Honorary Membership in the Institute."

When he received the Medal and accompanying certificates, Dr. Whitney said: "I thank you Mr. President."

To Sir James Hopwood Jeans, Dorking, England. Dr. James Barnes, sponsor.

The Chair recognized Dr. Barnes.

Dr. Barnes: "Mr. President: The Board of Managers of

The Franklin Institute on the recommendation of its Committee on Science and the Arts is unanimously of the opinion that a Franklin Medal be awarded to Sir James Hopwood Jeans, 'In recognition of his many fruitful contributions to mathematical physics, especially in the realms of the dynamical theory of gases and the theories of radiation, and of his challenging explanations of astronomical problems and illuminating expositions of modern scientific ideas.'

"Sir James was born in London, in 1877. He was educated at Trinity College, Cambridge, where he distinguished himself by being second Wrangler and Smith's prizeman. From 1905 to 1909 he was professor of applied mechanics at Princeton University. Here he showed himself to be an unusually gifted teacher by inculcating in the minds of his students a thorough knowledge of a difficult subject.

"Since his return to his native land he has held the following posts: Stokes Lecturer at Cambridge, Halley Lecturer at Oxford and Secretary of the Royal Society.

"He has been the recipient of the Royal Medal of the Royal Society, and the Gold Medal of the Royal Astronomical Society. He is a Fellow of the Royal Society. In 1928 he was knighted by the King in recognition of his outstanding scientific accomplishments.

"Sir James is the author of over a hundred articles in learned periodicals. In these papers he has analyzed some of the most difficult physical and astronomical problems, such as the equipartition of energy, Maxwell's law of the distribution of velocities among molecules, the stability of pear-shaped bodies rotating in compressible and incompressible fluids, the formation of binary stars, the nature of spiral nebulæ, the source of stellar energy and the evolution and radiation of gaseous stars. In addition he has written several volumes which are used successfully as text-books in many colleges.

"To the public he is probably best known as the author of the books entitled 'The Universe Around Us,' 'The Mysterious Universe' and 'The Stars in Their Courses.' In these he has shown that he possesses the remarkable ability of making the most abstruse theories seem clear to the intelligent layman, mainly through his logical development and apt analo-

gies. These books stir our imagination as well as give us a large amount of interesting information scientifically correct.

"Sir James concludes from his studies that the Universe appears to have been designed by a pure mathematician and operates according to mathematical laws. In this we believe he is undoubtedly correct. One of the most important of these mathematical laws is that, in an isolated system, the change of entropy with time is always positive so that ultimately the expanding Universe will reach a maximum, completely disorganized and in a state of thermodynamic equilibrium. Now the physicist takes a step farther and attempts to verify the conclusions of the mathematician and in so doing often discovers new laws of Nature. Apropos of this at this time is the well-known Michelson and Morley experiment. So that perhaps an astrophysicist, in the million million years to come, before the entropy reaches its maximum, will discover on a few of the stars, let's say a quadrillion, numerous Maxwell demons who daily violate the terrestial second law of classical thermodynamics. Thus there may arise, as has happened in the new quantum mechanics, a new cosmological thermodynamics;

> Theories come and theories go
> But facts go on forever.

"Mr. President—Sir James has come from England to be with us today. He honors us greatly by his presence. We ask you to bestow upon him our highest award, the Franklin Medal, and Certificate of Honorary Membership in The Franklin Institute. I, therefore, have the pleasure and honor of presenting to you, Sir, this famous astrophysicist, Sir James Jeans."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership, as follows:

"In recognition of this work which has had such a far reaching effect on the scientific development of the modern world, The Franklin Institute awards to you its Franklin Medal, the highest award in its power to give. As President of this Institute, it is my privilege to present this Medal to you and with it a Certificate of Honorary Membership.

"May I add, Sir James, a word of pleasure which it has

given us that you should have been able to cross the Atlantic in order to join our Medal Meeting."

Sir James expressed his gratitude for the award.

After the presentation of the Medals, two papers were read, having been prepared by the Franklin Medalists of the day.

In introducing the first speaker, Dr. W. R. Whitney, who presented a paper on "Research: Theory and Practice," [1] Mr. Hayward said:

"As we look at the scientific men in England and on the Continent of Europe, we sometimes feel in this country a little bit depressed at the fact that there seem to be so many more men in Europe who reach the high spots. We have our Michelson and a few such men but when you look at Europe and England it seems that they have more. We have one type of scientist who, I think, has done the work that has not been done anywhere else in the world and that is the man who devotes his whole life to pure science and yet keeps that pure science in touch with the practical everyday operations. Dr. Whitney, whom we have the honor to have with us, has done this as few others could do it in his work for the General Electric. Dr. Whitney."

The next speaker was Sir James H. Jeans, who read a paper entitled "The Origin of the Solar System." [2] Mr. Hayward, in presenting Sir James to the audience, said:

"I can add nothing to what Dr. Barnes has said except one personal thing, namely: That I have had the pleasure of spending the last twenty-four hours with Sir James and I can say that he is not only the great scientist but a very delightful gentleman."

After an expression of appreciation to the medalists and the audience for their attendance, the President declared the meeting adjourned.

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[1] See page 147.
[2] See page 135.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

COÖPERATION WITH FOREIGN NATIONAL LABORATORIES.

For many years the Bureau of Standards has coöperated with the leading foreign National Laboratories, notably those of Germany and England, in maintaining uniformity of those standards for which there has been no international coördinating agency. Uniformity of the fundamental standards of length and mass has been maintained by the activity of the International Bureau of Weights and Measures. The maintenance of many other standards, such as those for electricity, photometry, temperature, etc., has been left to the several national laboratories. The advantages of frequent intercomparisons of the national standards in promoting uniformity of standards were recognized at an early date, and there have been numerous interchanges of standards among the various laboratories. Recently a proposal of the bureau for an interchange of personnel between the national laboratories was accepted by the Physikalisch Technische Reichsanstalt and Prof. Dr. F. Henning, chief of the division of heat and pressure of the Reichsanstalt, came to the bureau to collaborate on problems of temperature measurement and in investigations of the use of black bodies as standards of light. To complete the exchange, Dr. G. W. Vinal of the Bureau of Standards, is now at the Reichsanstalt engaged in investigations of electric standards.

Professor Henning brought to the bureau two platinum resistance thermometers which were part of a group that had been used in an intercomparison (not yet completed) of the standards of the National Physical Laboratory of Great Britain, the Reichsanstalt, and the Bureau of Standards. He also brought standard thermocouples and some special lamps for which the current-temperature relation had been determined, so that means were available for making comparison over the entire range covered by the International Tempera-

* Communicated by the Director.

ture Scale.[1] The work done on the intercomparisons of the temperature scales illustrates very well the advantages of the modern tendency to use, wherever possible, standards which are reproducible from definitions. In comparing the Reichsanstalt's resistance thermometers with those of the bureau, for example, exactly the same procedure was followed as would have been necessary if all the working standards had been destroyed. The thermometers were first calibrated at the ice point, steam point, and the boiling points of sulphur and oxygen, and were then used to measure other temperatures, such as the freezing points of antimony, lead, tin and mercury, and the normal sublimation point of CO_2. The new calibrations and measurements were found to be in agreement with those previously made at the bureau or at the Reichsanstalt within 0.02° or 0.03° in all cases, and for most of the points, the agreement was very much better. Thus it was shown to be possible, in the course of a few weeks, to reëstablish the temperature scale with high accuracy, even if no calibrated standards were available at the start. Similar results were obtained in intercomparisons of thermocouples, and in measurements of high temperatures with optical pyrometers.

Professor Henning also collaborated in a new determination of the freezing point of iridium. The method used was the same as that used previously at the bureau for determining the freezing point of platinum, as described in Research Paper No. 326 in the June, 1931 number of the Bureau of Standards Journal of Research. This measurement is apparently the first accurate determination of this temperature, as the value found, 2452° C., is believed to be accurate within a few degrees, although it is about 100° higher than the previously accepted value for the melting point of iridium. Professor Henning is joint author of the paper in which this work is to be described.

Further measurements with black body standards of light were also made. A repetition of the measurements with the Waidner-Burgess standard[2] confirmed the results of the previous work. Measurements of the candle power of a black

[1] *B. S. Jour. Research*, Vol. 1, p. 635; 1928. R. P. No. 22.
[2] *B. S. Jour. Research*, Vol. 6, p. 1103; 1931. R. P. No. 325.

body immersed in freezing iridium resulted in a preliminary value of 1222 ± 10 candles per cm.^{2}, while the value calculated from the temperature was 1220 candles per cm.^{2} The value found, 1222 candles per cm.^{2} corresponds to a temperature of 2452.6° C. Thus the photometric determinations and the temperature measurements are concordant far within the limits of accuracy measurement.

While the scientific results obtained during Professor Henning's stay at the bureau are of great interest and value, an even more important result is to be found in the promotion of better understanding and closer coöperation between the national laboratories which will enable them to work more effectively in establishing and maintaining uniform standards. Although no formal arrangements have yet been made for continuing these exchanges of personnel, the highly successful results of this first venture indicate that such exchanges would be a most valuable addition to the programs of the national laboratories.

INTERNATIONAL COMMITTEE ON WEIGHTS AND MEASURES.

The regular biennial meeting of the International Committee on Weights and Measures held at Paris, April 10 to 18, 1931, was attended by Dr. S. W. Stratton, former director of the Bureau of Standards, who is the American member of this committee. Official reports of the meeting have not yet been issued, but informal reports indicate that satisfactory progress was made on several technical questions. In particular, the committee definitely adopted 20° C. (68° F.) as the normal temperature for adjustment of industrial standards for length measurements.

The committee also approved without change the resolutions regarding photometric and electrical units and standards submitted by its Advisory Committee on Electricity and Photometry. These resolutions were reported in full in *Technical News Bulletin* No. 164, p. 115 (December, 1930). In brief, the resolutions on photometry recommend the use of a "black-body" radiator as a primary standard of light, request other laboratories to give special study to the form of black-body operated at the freezing point of platinum which

has been developed at the Bureau of Standards, ask all countries to accept the unit of light known as the "International candle," propose that the national standardizing laboratories coöperate in establishing and maintaining the common unit, and that any future adjustment of its value be made only by international agreement approved by the committee, and express the hope that agreement may soon be reached on a standard method of measuring lights of diverse colors.

With regard to electrical units, the conclusions are that values for the ohm in use in different countries are so nearly in accord that no adjustments will be necessary until it is found practicable to go over in all countries to an ohm based upon absolute measurements. For the volt, however, present values are so discordant that they should be checked by measurements with the silver voltameter (Editors and printers: note that this is *not voltammeter*) as prescribed by the agreement under which the present international electrical units were established. (See following item for steps already taken to carry out this recommendation.)

INTERNATIONAL COMPARISON OF ELECTRICAL UNITS.

It has been known for several years that the values of the electrical units in use in different countries were not exactly in accord, but an exact determination of existing differences was difficult because the standards could not be transported between countries without undergoing some changes. A new type of resistance standard developed at the bureau has, however, proved free from these changes in transit. By means of such resistance coils and of standard cells carefully carried by hand, direct comparisons have been made between the Bureau of Standards and the national laboratories of Germany and of Great Britain several times during the last three years. These comparisons have shown that the British ohm is at least 2 parts in 100,000 larger than the American, while the German unit is about the average of the other two.

The British volt is likewise 2 parts in 100,000 larger than the American, but for this unit the German values are 6 parts

in 100,000 below the American, or 8 below the British. In measurements of power or of energy this discrepancy is practically doubled; the German watt is 13 parts in 100,000 smaller than the American, and 15 below the British unit.

In accordance with recommendations of the International Committee on Weights and Measures (see preceding item) measurements with silver voltameters to determine the correct "international" value for the volt have been begun in several national laboratories. Fortunately it has been found possible to arrange for direct coöperation between the three laboratories mentioned; Dr. George W. Vinal of the Bureau of Standards and Dr. J. E. P. L. Vigoureux of the British National Physical Laboratory are now at the German Physikalisch-Technische Reichsanstalt carrying out voltameter measurements and comparing groups of standard cells.

CALIBRATION OF STEEL TAPE BENCH.

During recent months a number of invar base-line tapes have been calibrated, when supported throughout, to determine the lengths of the 5-meter intervals. This provided an opportunity to check the 5-meter intervals of the bureau's bench standard ("Bench I"). The results are shown in the following table, values obtained in 1912 and 1922 being shown for comparison:

Interval.	Element of Calibration of Bench I (Basis that 0 to 50 m. has Zero Correction).		
	1912.	1922.	1931.
0 to 5 m.	+ 0.07 mm.	+ 0.18 mm.	+ 0.17 mm.
0 to 10 m.	− 0.01	+ 0.19	+ 0.19
0 to 15 m.	− 0.28	− 0.08	− 0.10
0 to 20 m.	− 0.22	− 0.06	− 0.10
0 to 25 m.	− 0.16	− 0.02	− 0.06
0 to 30 m.	− 0.29	− 0.14	− 0.23
0 to 35 m.	− 0.10	− 0.07	− 0.14
0 to 40 m.	− 0.17	− 0.09	− 0.05
0 to 45 m.	− 0.08	− 0.03	− 0.08
0 to 50 m.	0.00	0.00	0.00

The calibrations in 1912 and 1922 were direct calibrations of the bench, using a least squares reduction of the observations which were made with one steel tape (B. S. No. 1313).

In 1931 the measurements were made for the primary purpose of obtaining corrections to the tapes for which values to the 5-meter intervals are reported to the nearest 0.1 millimeter; but using the mean of eight absolutely different determinations gives a very precise value. Probable errors must be used with caution in such a case as this. The least accurate value appears to be for the interval 0 to 35 for which the element of calibration has a probable error as computed from the eight deviations of 0.013 mm. (13 microns). The interval 0 to 5 meters was apparently determined with the greatest accuracy, the probable error for its element of calibration being only 0.005 mm. (5 microns).

The correction to the 50-meter interval on this bench was also re-determined recently. Measurements were made using eight tapes, seven of which were the same as used in the calibration of the subintervals. These eight tapes had been measured on the geodetic tape comparator just prior to this investigation, and the length of each of the tapes supported throughout was computed using the customary catenary formula.

The length of the 50-meter interval of this bench is now found to be 50.01136 meters at 20° C. Taking into account simply the deviations of the 8 sets of measurements, the probable error of this result is 0.00002 meter (0.02 mm. or 20 microns). The average deviation is 0.00008 meter, and the maximum deviation 0.00012 meter. Since the 50-meter interval of the bench would change in length by 0.00002 mm. with a change in temperature of 0.03° C., the result is more precise than would be expected.

This 50-meter interval had been previously measured in 1909 and in 1922. The values at 20° C. are

1909	50.01120 meter
1922	50.01129
1931	50.01136

The 1909 measurements were made with 16 invar tapes, a total of 58 separate values being obtained with a probable error of the mean of these comparisons of 0.000011 meter (0.011 mm. or 11 microns) and a computed probable error of

the final total length of 0.000030 meter (0.030 mm. or 30 microns).

In 1922 the measurements were made with six invar tapes by comparison with Bench II which had been tested a short time before. The probable error of the comparison of the two benches was 0.00003 meter (0.03 mm. or 30 microns).

In examining these results, it appears that a check on the calibration of the tape benches should be carried out about once a decade. These results, combined with the results of other tests made in recent years on the bureau's bench standards are proof that these steel tape benches are calibrated to an accuracy which is not only entirely adequate for the purpose but which is also entitled to high rank among physical measurements.

METERING LARGE VOLUMES OF AIR.

A recent investigation of meters used for measuring large volumes of gas will be described in the July number of the *Bureau of Standards Journal of Research.* In this study a gas holder, 165 feet in diameter, was used as an absolute standard in testing a rotary displacement gas meter, a 24 by 12 inch Venturi meter, and 4 square edged, thin plate orifices installed, one at a time, in a smooth 24 inch pipe. The tests were made with air.

The temperature of the air in the holder, measured by electrical thermometers, was controlled by flooding the holder with a continuous stream of water, pumped up from the tank and allowed to run down again into the tank over the crown and sides. The experiments were made at night. After the holder had been filled with air by a centrifugal booster, the connections were changed so that the booster withdrew air and forced it along the line in which the meters to be tested were installed in series. The rate of delivery was computed from the dimensions and rate of fall of the holder, and observations of pressure and temperature.

The rated capacity of the rotary displacement meter was 200,000 cubic feet per hour and the holder was undesirably large for rates lower than this, so that the precision of the measurements was less than for higher rates. Eight tests at

rates between 38,000 and 173,000 cubic feet per hour gave a mean coefficient of 0.994, indicating that the meter ran 0.6 per cent. fast with respect to the holder. The mean departure from the mean was ± 0.4 per cent.

Sixteen determinations of the adiabatic discharge coefficient of the Venturi, at rates between 307,000 and 612,000 cubic feet per hour, gave values from 0.986 to 0.994, with a mean of 0.990, a mean departure of ± 0.003, and no evidence of a systematic run. If two values which appeared intrinsically less reliable than the others were omitted, the mean was 0.989 and the mean departure was ± 0.002. The limiting factor in the precision was in the measurement of the fall of the holder rather than the temperature; and the four tests in which the measurements of the fall of the holder at the ends of two perpendicular diameters were most consistent gave the values C_a = 0.988, 0.988, 0.987, and 0.988. The values of the Reynolds number, referred to the throat, varied in the 16 experiments between 660,000 and 1,290,000 with a mean of 870,000, the values for the 24 inch pipe being about half as large.

After the Venturi had thus been standardized, it was used as a meter in testing 10 additional orifices. Supplementary observations were also made on the distribution of pressure along the pipe wall near the orifices, with at least two different rates of flow for each of the 14 orifices.

The most important results of the investigation are those relating to the discharge coefficients of the orifices. When these are so reduced as to be comparable with values for water recently published by R. Witte, the agreement is very good. They may be summarized as follows:

Let C be the discharge coefficient, defined in terms of "British absolute" or cgs units by the equation

$$M = C A\sqrt{2(p_1 - p_2)\rho_1}$$

where M = the mass flow; A = the area of the orifice; p_1 and p_2 = the upstream and down stream pressures observed at points one inch from the orifice plate; and ρ_1 = the density of the air at p_1 and the upstream temperature.

Let β = the ratio of the diameter of the orifice to that of the pipe; $x = (p_1 - p_2)/p_1$; and $\gamma = C_p/C_v$ = the specific

heat ratio of the gas. Then the results obtained may be represented within the limits $\chi < 0.08$ and $0.2 < \beta < 0.77$ by the equation

$$C = KY,$$

in which

$$K = 0.597 + 0.41\,\beta^4$$

and

$$C = 1 - (0.40 + 0.46\,\beta)\frac{\chi}{\gamma}.$$

These relations do not hold outside the stated limits of β nor for other locations of the pressure holes, but they probably do hold for considerably higher values of the fractional differential x.

VISIBLE AND ULTRAVIOLET ABSORPTION SPECTRA OF CAROTIN AND XANTHOPHYLL.

The absorption spectra of equal molecular concentrations of pure carotin and xanthophyll in alcohol-ether solution have been studied throughout the visible and ultraviolet spectral range, and the changes in the absorption spectra followed as the pigments were allowed to oxidize slowly in solution.

The absorption spectra of the pure unoxidized pigments have essentially the same structure and consist each of three groups of overlapping and partially resolved component bands. The bands for xanthophyll are sharper and closer together than the corresponding bands for carotin. By far the strongest group of bands for each pigment is located in the blue and violet regions of the visible spectrum. The frequencies (frequency $= 3 \times 10^5$/wave-length in millimicrons) of the components of these strong band-groups are 602, 636, 672, 708, 745 for xanthophyll, and 589, 625, 666, 712, 764 for carotin. The ultraviolet band-groups are relatively very weak, compared with the visible group, and the resolution into components is not so definitely indicated. The groups are centered at frequencies of 903 and 1119 respectively, for xanthophyll, and at 882 and 1098, respectively, for carotin. It is found, that, within the range of uncertainty of the experimental data, the three groups of component bands for each pigment form a single regular sequence of bands the frequencies of which are

well represented by the parabolic equation

$$\nu - \nu_0 = a\,(n - n_0)^2,$$

wherein ν_0, n_0, and a are constants, and n takes successive integral values. A periodic variation of intensity in the above progression of component bands gives rise to the appearance of the definite band-groups and to the characteristic form of the absorption curves.

During slow oxidation in solution the spectrum of each pigment is observed to pass through the same series of changes until oxidation is complete. The carotin spectrum does not become identical with that of pure xanthophyll during this process; so that carotin is not oxidized to xanthophyll, as contended by some previous investigators.

The oxidation process proceeds in two definite stages which are the same for both pigments. The first stage corresponds to a marked increase in the intensity of the mid-ultraviolet band-group, accompanied by a small decrease in the intensity of the other bands. This characteristic change provides a sensitive test for incipient oxidation. During the second stage of the oxidation process there occurs a very rapid change in the structure of the spectrum. The visible band-group rapidly disappears along with a more gradual fading of the ultraviolet bands until the characteristic absorption spectrum is entirely suppressed. These oxidation stages of hydrogenation observed by Zechmeister and his associates [1] and attributed to the saturation of two different groups of double bonds in the molecule.

The oxidation experiments also lend support to the contentions of Schertz [2] and others that the series of yellow xanthopylls described by Tswett as different pigments represent only different stages in the oxidation of a single pigment. Tswett's description of his xanthophylls is based principally on the positions of absorption bands in the visible spectrum. These positions are shown to correspond closely to successive changes in the absorption spectrum of xanthophyll during the slow oxidation process in solution.

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[1] *Ber. d. Deut. Chem. Gesell.*, *61*, 566, 1534, 2003; 1928: *62*, 2226; 1929.
[2] *Plant Physiology*, *4*, 337; 1929.

The complete report on this subject will be published in the July number of the Bureau of Standards Journal of Research.

DOMINANT WAVE-LENGTH AND PURITY OF COLOR STIMULUS.

In order to compute the dominant wave-length and purity of a color stimulus by means of the "excitation" data of the Optical Society of America, two values must be obtained by interpolation. The adoption of the osculatory formula for this interpolation permits the computations to be made with perfect reproducibility. Each of the O. S. A. curves by this method is represented as a series of parabolas of the fifth degree which join at the values specified at every 10 millimicrons so as to have a common slope and curvature at the junction point. Interpolated values have been computed according to this formula for every millimicron. Tables giving these data will be published in the July number of the *Bureau of Standards Journal of Research.*

MEASUREMENT OF LENARD RAYS.

An investigation is described in the July number of the *Bureau of Standards Journal of Research* in which the correct measurement of the electron output—Lenard current—from high voltage cathode ray or Lenard ray tubes is attempted.

The evidence presented shows that a faraday chamber of proper dimensions may be used to measure the Lenard ray current, which at any point is shown to be a linear function of the total tube current. The open plate method of measuring Lenard currents yields results which are consistently too low, although under the conditions here used they bear a constant relationship to the faraday chamber measurements. The open plate measurements are therefore also a linear function of the total tube current. The condenser method of measurement (Thaller) yields measurements above or below those of the faraday chamber depending upon the relationship of the atomic numbers of the two plates. Moreover the current measured by this method is not a linear function of the total tube current and hence does not bear a constant relation-

ship to the faraday chamber measurements under the conditions used. Measurements of the range of scattered electrons from Lenard tubes operating at about 160 kv. peak, indicate a maximum of about 15 mm. in air which is equivalent to an energy of about 60 electron kilovolts. By means of a variable faraday chamber described, it is possible to obtain a measure of the velocity distribution of the scattered electrons.

DENSITY VERSUS COMPOSITION OF SODA-SILICA GLASSES.

The studies on the relations between composition and density of soda-silica glasses has been continued and some conclusions quite different from those previously reported in *Technical News Bulletin* No. 159 (July, 1930) have been reached. The method of preparation of the glasses is described in the previous reference. Fourteen additional glasses were made and it now seems that relations between density and composition can be more accurately expressed by a series of linear equations than by the exponential equation formerly given. The specific volume (reciprocal of density) can be computed from $V = a_1A + b_1B$, in which V is specific volume, A and B are the percentages of silica and soda respectively and the values of the constants a_1 and b_1 are as follows in the indicated silica ranges:

Silica Range Per Cent.	a_1.	b_1.
50 –59.4	0.0042520	0.0035370
59.4–66.3	.0043028	.0034628
66.3–74.9	.0043922	.0032872
74.9–100	.0045400	.0028460

Of the 27 glasses on which these conclusions are based, five were in the first group, six in the second, seven in the third, and nine in the fourth. The average deviation $\times 10^{-4}$ in these four groups is 9, 7, 6, and 8 respectively, the average deviation for the entire series being 7. The maximum deviation is 17.

It is interesting to note that the limiting silica values for the four groups mentioned above correspond quite closely to definite molecular ratios between silica and soda.

Similar results were obtained for relations between compositions and refractivities of these glasses and it seems quite

probable that changes in density and refractivity of soda-silica glasses with composition cannot be expressed by a single exponential equation or a single smooth curve, but that they should be expressed by simple equations or straight lines intersecting at certain molar compositions.

ANALYSES OF SALTS USED FOR CURING HIDES AND SKINS.

Stains and blemishes on hides and skins are a source of loss and annoyance to producers of leather. The presence of these imperfections often prevents the finishing of the leather in the desired colors and also causes a lack of uniformity in color which necessitates a lower quality grading of the material than would otherwise be the case. Unsatisfactory methods of curing hides and skins contribute to the formation of stains, and troubles of this nature have been attributed to impurities existing in the salts used. In considering the seriousness of the problem, the Calf Tanners' Association raised the question as to the amounts of impurities occurring in the original salt (as distinguished from used salt) and requested the coöperation of the Bureau of Standards in securing the information.

Twenty-nine representative samples of mined and evaporated salts produced in different geographical locations within the United States and used for curing hides and skins were selected for examination. The minimum and maximum amounts of the different chemical constituents which were determined quantitatively are given in the following table.

Minimum and Maximum Amounts of the Important Constituents of Rock and Evaporated Salts.

Chemical Constituents.	Type of Salt.			
	Rock.		Evaporated.	
	Minimum, Per Cent.	Maximum, Per Cent.	Minimum, Per Cent.	Maximum, Per Cent.
Moisture	0.01	0.12	0.17	2.51
Insolubles	0.20	1.90	0.00	0.50
Iron (Fe)	0.0000	.0003	.0000	.0002
Calcium (Ca)[1]	.09	.41	.22	.49
Magnesium (Mg)[1]	.00	.01	.01	.08
Sulphate (SO_4)[1]	.12	.74	.42	.67
Carbonate (CO_3)	.00	.00	.00	.05

[1] In four samples of evaporated Ohio River Salt, the calcium varied from 0.55 to 2.01, the magnesium varied from 0.24 to 1.00, and no sulphate was present.

Four samples were examined for insoluble iron and the amounts found varied from 0.0017 to 0.0123 per cent. Aluminum and silicate did not exceed 0.005 per cent. in any sample. Qualitative tests showed arsenic and phosphate to be absent from all samples and boron to be present in minute quantities in two samples.

The work also included the analyses of six samples of foreign salts. One of these was a commercial denatured salt which contained 0.07 per cent. of oil as determined by extraction with petroleum ether. Another salt was denatured with sodium carbonate as indicated by the high carbonate content found of 2.63 per cent.

The results are presented for the information of those interested in the influence of curing salts upon the formation of stains and blemishes. The report of this work was published in the *Journal of the American Leather Chemists Association*, Vol. XXVI, No. 6, June, 1931.

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LIBRARY NOTES.

RECENT ADDITIONS.

CLAASSEN, H. Die Zuckerfabrikation mit besonderer Berücksichtigung des Betriebes. Sechste Auflage 1930.

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STIRLING, ROBERT. The Gas Air-Lift Pocket Book. 1929.

VOSS, WALTER C. Architectural Construction. Volume 1 with collaboration of R. C. Henry; Volume 2, Books 1–2, with that of E. A. Varney. 1925–1927.

BOOK REVIEWS.

THE VITAMINS. By H. C. Sherman, Mitchill Professor of Chemistry, Columbia University and S. L. Smith, Senior Chemist, Office of Experiment Stations, U. S. Department of Agriculture. Second edition. American Monograph Series, 575 pages, illustrations, 8vo. New York, The Chemical Catalog Co., Inc., 1931. Price $6.00.

Vitamin—an indispensable something found in foods in quantities that, to a chemist, seems to have attained an irreducible minimum. Politics is not the only thing that makes strange bed fellows. The science of nutrition has brought

together under the term "vitamin" a number of substances apparently of most diverse chemical structure. From the viewpoint of a chemist these vitamins might be likened unto pin points: Most difficult to observe visually but, when applied to an appropriate spot on the human body, can exert a stimulating influence out of all proportion to their magnitude.

This second edition of "The Vitamins" comes nine years after the first which might easily be classed as one of the charter members of the American Chemical Society Monographs. Membership in this selective family almost precludes its adoption for popular perusal. However, if one wishes to follow the pyramidal development of vitaminic knowledge, behold, the book.

The authors of this volume have faithfully followed the traditions and, with the extraordinarily great amount of labor attendant to such accomplishment, have given us an all-embracing treatise upon "The Vitamins." They wisely have made no attempt to rearrange the order of events but have listed them in their chronological sequence. They tell the vitamin story from A to G and discuss them individually in the order: B, G, C, A, D and E. The first three are often classed as water-soluble, the three latter as fat-soluble. One could discourse at length upon the many interesting discoveries arising from vitamin researches: How the vitamin B was shown to consist of two and perhaps even three separate vitamins; how vitamin D can arise from the ultraviolet irradiation of ergosterol, a non-saponifiable fat; how it was discovered that the yellow coloring matter of carrots provide the liver with raw material for the manufacture of vitamin A; the very interesting but wholly different influences exerted upon the reproductive processes by vitamin A and the recently established vitamin E. But, space and time will not permit and anyway, why not read for yourself?

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 375. Full-Scale Tests of Metal Propellers at High Tip Speeds, by Donald H. Wood, 22 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price fifteen cents.

This report describes tests of 10 full-scale metal propellers of several thickness ratios at various tip speeds up to 1,350 feet per second. The tests were made in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics at Langley Field, Virginia.

The results indicate no loss of efficiency up to tip speeds of approximately 1,000 feet per second. Above this tip speed the loss is at a rate of about 10 per cent. per 100 feet per second increase relative to the efficiency at the lower speeds for propellers of pitch diameter ratios 0.3 to 0.4. Propellers having sections of small thickness ratio can be run at slightly higher speeds than thick ones before beginning to lose efficiency.

Report No. 378. Comparison of Full-Scale Propellers having R. A. F.-6 and Clark Y Airfoil Sections, by Hugh B. Freeman, 20 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price ten cents.

In this report, the efficiencies of two series of propellers having two types of blade sections are compared. Six full-scale propellers were used, three having

R.A.F.-6 and three Clark Y airfoil sections with thickness/chord ratios of 0.06, 0.08, and 0.10. The propellers were tested at five pitch settings, which covered the range ordinarily used in practice. These tests were conducted in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics.

The propellers having the Clark Y sections gave the highest peak efficiency at the low pitch settings. At the higher pitch settings, the propellers with the R.A.F.-6 sections gave about the same maximum efficiency as the Clark Y propellers and were more efficient for the conditions of climb and take-off.

Report No. 381. Static, Drop, and Flight Tests on Musselman Type Airwheels, by William C. Peck and Albert P. Beard, 20 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price fifteen cents.

This investigation was conducted at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics during the period from January to July, 1930, for the purpose of obtaining quantitative information on the shock-reducing and energy-dissipating qualities of a set of 30 by 13-6 Musselman type airwheels. The investigation consisted of static, drop, and flight tests. The static tests were made with inflation pressures of approximately 0, 5, 10, 15, 20 and 25 pounds per square inch and loadings up to 9,600 pounds. The drop tests were made with inflation pressures of approximately 5, 10, 15, 20, and 25 pounds per square inch and loadings of 1,840, 2,440, 3,050, and 3,585 pounds. The flight tests were made with a VE-7 airplane weighing 2,153 pounds, with the tires inflated to 5, 10, and 15 pounds per square inch. The landing gears used in conjunction with the airwheels were practically rigid structures.

The results of the tests showed that the walls of the tires carried a considerable portion of the load, each tire supporting a load of 600 pounds with a depression of approximately 6 inches.

The shock-reducing qualities, under severe tests, and the energy-dissipating characteristics of the tires, under all tests, were poor. The latter was evidenced by the rebound present in all landings made. In the severe drop tests, the free rebound reached as much as 60 per cent. of the free drop.

The results indicate that a shock-reducing and energy-dissipating mechanism should be used in conjunction with airwheels.

ANNUAL SURVEY OF AMERICAN CHEMISTRY, edited by Clarence J. West, Director, Research Information Service, National Research Council, Volume V, 1930. 629 pages, 12mo, New York, The Chemical Catalog Company, Inc., 1931. Price $5.00.

The reviewer recognizes the "Annual Survey of American Chemistry." A five-year-old member of that rapidly expanding group of publications in the field of American chemistry. A member that has grown at the rate of almost 100 pages per year since its beginning. As the title indicates, the book is a collection of writings describing the advances in some particular phase of chemistry and written by chemists of great capabilities in these their respective fields.

As we glance over the table of contents we find that the majority of subjects return year after year and by virtue of the extensiveness of their field always

bring something new and interesting. Subjects referring to more limited fields appear for some single volume and are gone. It is hardly appropriate to include here the table of contents of this fifth volume. However, we cannot resist comparing this volume with that of last year and calling attention to these added subjects: Subatomic Phenomena, Physical Methods in Analytical Chemistry, The Rare Earths, Cement and Concrete, Chemistry of the Silicates, Synthetic Yarns, Chemical Economics, while simultaneously noting omission of the subjects: Oxidation and Reduction Potentials, Heavy Acids, Chromium, Stereochemistry, Ceramic Products, Rayon, Leather, Synthetic Resins.

The book is a most excellent example of its type representing the wholehearted cooperation of the authors and therein lies the secret of its success. What a pity a book of this type could not be made universal in respect to the various fields of chemical development that it covers. True, England accomplishes something of this nature through two separate publications, both of which leave something to be desired.

T. K. CLEVELAND.

THE HISTORY AND WORK OF HARVARD OBSERVATORY: 1839–1927. By Prof. Solon I. Bailey. xiii–301 pages, with 22 plates, 8vo. New York, The McGraw-Hill Book Co., 1931. Price $3.50.

To a great extent, more than of any other institution, the history of the Harvard College Observatory is the history of astronomy in America. It was established in 1839. Of observatories still existing in the United States only four can claim a greater antiquity; namely, Yale (1830), Williams (1836), Wesleyan (1836) and Western Reserve (1838). With the installation, in 1847, of a 15-inch refracting telescope, the largest in existence at that time, the Harvard Observatory assumed a leading position among the world's observatories. Ever since, it has remained in the very front rank.

In view of these facts, it is rather surprising that, up to now, there has been no adequate history of the institution. However, this can be understood when it is recalled that the observatory staff has been too busy, contributing to astronomical progress, to take time to resurrect the past. The late Dr. E. C. Pickering, director of the Observatory until his death in 1919, suggested that such a history be prepared by Prof. Bailey, whose connection with the Observatory since 1887 peculiarly fitted him for such a labor. The suggestion was renewed by Dr. Harlow Shapley, the present director, and the result is the present work, which Prof. Bailey wrote since his retirement in 1925. It is sad to chronicle that the author died, at the age of 77, on June 5, less than a week after its publication.

The book is divided into three parts. The first is an "Historical Outline," summarizing the development of the Observatory, and the steps that led up to it. Even before it was established, Harvard displayed an interest in astronomy, for John Winthrop, professor of mathematics and natural philosophy from 1738 to 1779, taught astronomy and made important observations with small instruments. He was contemporary with David Rittenhouse, who was making important observations in Philadelphia at the same time.

The present Observatory was established in 1839 by William C. Bond, its first director. At first it was in the Dana House, where Bond lived, but in 1843 the appearance of a bright comet called attention to the poor facilities at Bond's disposal, and the present site was occupied the year later. In 1847 the great

telescope was installed, and many important discoveries were made with its aid, such as Bond's discovery of the inner "crepe" ring of Saturn. After the death of the elder Bond, in 1859, his son, George P. Bond, assumed the directorship, a position which he held until he died in 1865. Then Joseph Winlock took the helm. Winlock died in 1875. In 1877 a young physicist, only 30 years of age, was made director. This was Edward Charles Pickering. During the 42 years that he served as director, the observatory entered into what might be called the modern period, in which it has had its greatest development. Bond had already made some of the first astronomical photographs, and under Pickering there was created the library of celestial photographs, now including over 200,000 negatives, that is one of the observatory's most important features. Mainly interested in astrophysics, he began the photographic work with spectra that has contributed so largely to astronomical knowledge. The Henry Draper Catalog of stellar spectra, the classification being done by Miss Cannon, was started. In 1890, a southern station was established at Arequipa, Peru, in order that the work of the observatory might include the entire celestial sphere.

After Pickering's death in 1919, Dr. Bailey himself served as acting director until 1921, when Dr. Harlow Shapley, the present incumbent, was appointed to the post. Under his guidance, the progress has been as rapid as at any time in the past, and the signs now point to an even greater acceleration in the future. The southern station was moved to Mazelspoort, South Africa, in 1926, and a 60-inch reflecting telescope, the largest in the southern hemisphere, was ordered for it shortly afterwards. Very recently it has been decided to install another 60-inch reflector at some place convenient to Cambridge, and so the observatory will not lack instrumental facilities.

In Part II we find more detailed discussions of the scientific problems that have engaged the attention of the observatory. Spectroscopy, photometry, astronomical photography, meteorology, studies of the planets, of comets, work on the nebulæ, and, in recent years, on the super-galaxies, greatest of all known astronomical systems—these are but a few of the fields in which valuable contributions to knowledge have been made. Biographical sketches of the most important past members of the staff, a complete list of all members, and an account of the principal benefactors of the observatory comprise Part III, the concluding section.

It is hard to imagine an astronomical library with any pretense to completeness lacking this volume, or, for that matter, any of the Harvard Observatory Monographs, of which this work is number 4. But even though it is of particular interest to astronomers, it will afford fascinating reading to anyone interested in the progress of American science, and it should be a source of inspiration to the present generation. In its more material aspects, the book is a credit to all concerned; the binding and printing are all that would be expected of publishers of such high standing, and a complete index makes it easy to consult.

JAMES STOKLEY.

PUBLICATIONS RECEIVED.

An Introduction to Organic Chemistry, by Roger J. Williams, second edition, 585 pages, diagrams, 8vo. New York, D. Van Nostrand Company, Inc. Price $3.50.

Harvard Observatory Monographs, No. 4, The History and Work of Harvard Observatory, 1839 to 1927, An Outline of the Origin, Development, and Researches of the Astronomical Observatory of Harvard College, together with Brief Biographies of Its Leading Members, by Solon I. Bailey, 301 pages, plates, 8vo. New York, McGraw-Hill Book Company, Inc., 1931.

Fundamentals of Electricity and Magnetism, by Leonard B. Loeb, 432 pages, diagrams, 8vo. New York, John Wiley & Sons, Inc., London: Chapman & Hall, Ltd., 1931. Price $4.00.

The Nature of a Gas, by Leonard B. Loeb, 153 pages, tables, diagrams, 8vo. New York, John Wiley & Sons, Inc., London: Chapman & Hall, Ltd., 1931. Price $2.50.

National Research Council, Bulletin No. 80, Physics of the Earth—IV. The Age of the Earth, by the Subsidiary Committee on the Age of the Earth, 487 pages, diagrams, tables, 8vo. Washington, The National Academy of Sciences, 1931. Price $5.00.

National Advisory Committee for Aeronautics, Sixteenth Annual Report, 1930, including Technical Reports Nos. 337 to 364, 787 pages, tables, diagrams, illustrations, quarto, Washington, Government Printing Office, 1931. Price $3.00. Technical Notes, No. 382, Basic Requirements of Fuel-Injection Nozzles for Quiescent Combustion Chambers, by J. A. Spanogle and H. H. Foster, Langley Memorial Aeronautical Laboratory, 6 pages, diagrams, quarto. Washington, Committee, 1931.

U. S. Bureau of Mines, Mineral Resources of the United States, 1928, by Frank J. Katz, Part I—Metals, Part II—Non-Metals, two volumes, illustrations, tables, 8vo. Washington, Government Printing Office, 1930. Price, part I, $1.50; part II, $1.25.

Bell Telephone Laboratories, Monographs: No. B-560, Statistical Method in Engineering, by W. A. Shewhart, 8 pages, diagrams, 8vo. B-563, Indicating Meter for Measurement and Analysis of Noise, by T. G. Castner, E. Dietze, G. T. Stanton, and R. S. Tucker, 18 pages, illustrations, 8vo. B-564, Sound Pictures, Fundamental Principles and Factors which Affect Quality, by Franklin L. Hunt, 9 pages, 8vo. B-565, On the Art of Metallography, by Francis F. Lucas, 34 pages, illustrations, plates, 8vo. B-566, A Direct Reading Audio-Frequency Phase Meter, by W. R. MacLean and L. J. Sivian, 15 pages, diagrams, 8vo. New York, 1931.

Royal Institution of Great Britain, Weekly Evening Meeting: February 6th, The Internal Mechanics of the Trade Slump, by J. M. Keynes, C.B., 6 pages. 8vo. February 20th, Prehistory in the Light of Genetics, by J. B. S. Haldane, M.A., 16 pages, maps, 8vo. March 6th, Ozone in the Upper Atmosphere and its Relation to Meteorology, by G. M. B. Dobson, D.Sc., 11 pages, diagrams, 8vo. March 27th, Helium and Its Properties, by Lord Rutherford of Nelson, 8 pages, 8vo. May 29th, The Future of the Human Race, by The Very Rev. W. R. Inge, 22 pages, 8vo. 7 pamphlets, London, Royal Institution, 1931.

Interstate Commerce Commission, In the Matter of Increase in Freight Rates and Charges, Statement and Application of the Steam Railroad Carriers of the United States, 20 pages, 8vo. Answer of Petitioners to Order of the Commission of June 19, 6 pages, 8vo. New York, E. W. Traver, 1931.

CURRENT TOPICS.

A Small Apparatus for the Production of Very Low Temperatures. M. RUHEMANN. (*Zeit. für Physik*, Vol. 65, p. 67.) The liquefaction of the gas helium has ceased to be a recondite matter of interest only to the limited circle of physicists and has become worthy of record in the newspapers as was true in April, 1931, when attention was directed to the alleged rivalry of different institutions for priority in the liquefaction of this element. Hitherto liquid helium has been produced in a very few laboratories notably in those of the universities of Leyden and Toronto. When in 1924 at the meeting of the British Association for the Advancement of Science a vessel containing liquid helium was placed on the lecture table in the physical laboratory of the University of Toronto many, perhaps most, of the audience of scientists had never previously seen this most difficult product of liquefaction. The cost and complexity of the necessary apparatus have exceeded the resources of most laboratories. When liquid hydrogen or liquid helium have been produced and used in experimentation a large part of the cold liquid has been expended in cooling accessory parts of the apparatus. The author has used the resources of the Physico-chemical Laboratory of the University of Berlin to make available a small piece of apparatus in which, without the use of a compression pump even helium may be liquefied. "The construction of the apparatus can be accomplished in the workshop of any laboratory in a few days and without considerable expense."

He uses Linde's method. A Dewar bulb 58 mm. in diameter and 400 mm. long contains a cylinder holding the chief parts of the device, viz., the spiral coils, one within the other, through one of which the incoming gas flows to the expansion valve where a part of it is liquefied and through the other of which the expanded gas makes its escape. If hydrogen is to be liquefied the Dewar bulb contains liquid air, while liquid hydrogen fills it, if liquid helium is the aim. Since helium from America can now be obtained in Europe in containers under a pressure of 100 or more atmospheres no initial compression is needed. After the parts inside of the Dewar flask have assumed the temperature of the contained liquid and the compressed gas begins to flow from its container only from 5 to 7 minutes are needed to reduce the temperature below the

expansion valve to that of boiling hydrogen or to that of boiling helium respectively, according to the gas flowing.

With liquid air in the Dewar flask the following shows the relation of duration to temperature, t being the number of minutes after the beginning of gas flow and T the absolute temperature at the valve.

t	0	1	2	3	4	5
T	86°	78°	70°	53°	35.8°	20.4°

After liquid hydrogen or liquid helium has collected in a vessel below the valve a reduction of pressure on the liquid causes the temperature to drop to 13° and 1.9° abs., respectively.

G. F. S.

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